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Development Division Report on the Evaluation of the 6-Hour Cycle Pre-Implementation Test for the NMC FINAL Cycle

Armand J. Desmarais
Paul L. Lemar
Robert J. van Haaren
Development Division

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Introduction

For many years the normal cycle-time for analysis/forecast systems at NMC has been 12 hours, i.e., analyses performed at 00 and 12 GMT. These analysis times agree with some of the synoptic times of upper-air (radiosonde and pilot balloon) and surface observations made throughout most of the world. Besides these observations, numerous aircraft reports are also available but are basically asynoptic. In the early 70's, NMC began to receive more asynoptic meteorological information (cloud patterns, estimates of winds from picture pairs and cloud-top blow offs, moisture estimates, tropospheric and stratospheric vertical temperature soundings) from polar-orbiting and geo-stationary satellites. In the mid 70's we have seen data from TWERLE, constant pressure balloons, drifting buoys, and others, coming into the scene for consideration in analysis schemes...and the beat goes on! As more and more asynoptic data becomes available, we believe it becomes important to reduce the time-window for asynoptic observations used in analysis procedures. Currently, NMC allows for the use of asynoptic data which may be as much as 6 hours off-time in operational analyses. Some attempt is made in the LFM analysis to correct the asynopticity of VTPR (McMillin, et al, 1973) soundings with the use of a time-tendency correction (Desmarais, 1972); however, this procedure is not used in the Flattery global analysis scheme (Flattery, 1971) which provides the operational and final analyses.

The Flattery analysis scheme currently used in the NMC considers all conventional synoptic observations and all VTPR and aircraft reports within 6 hours of synoptic time during the first 5 iterations; thereafter, only data within 3 hours of synoptic time are used during the next 4 iterations. In effect, the analyses will reflect the influence of any data which may have been 3 to 6 hours off-time, unless additional on-time (within 3 hours) observations are available in the same geographical area--and levels--for consideration during the final 4 iterations. Of course, in some regions of the world usually devoid of observations, a single off-time report is usually the only information available to help to describe the state of the atmosphere. However, 06 and 18 GMT surface observations are not used in the 12-hour cycle.

To diminish the impact of using upper-air observations as much as 6 hours off-time in the NMC 12-hour cycles, a 6-hour cycle for the global analysis/forecast system was designed and tested in 1974 as part of the NASA Data Systems Test (DST) conducted within Development Division (O'Neil, Desmarais, Bonner, 1974). In this test, only data within 3 hours of synoptic time were considered to be on-time. The analysis/forecast system was run for a couple of weeks, and during the test some problems were uncovered in the analysis/forecast system: frequent stratospheric exhaustions in the forecast model

(Stackpole, et al, 1974), and unrealistic analyses in the Southern Hemisphere due, mainly, to bad first guesses from previous forecasts. In the interim, many changes have been made and a stable system has been demonstrated.

Configuration of the Analysis/Forecast System for the 6-Hour Cycle Pre-Implementation Test

During the summer of 1975, Development Division conducted a 6-hour cycle experiment using observational data from April 1975. The configuration of the 6-hour analysis/forecast cycle was identical to the then operational final cycle except the update frequency was doubled. The 6-hour cycle showed some disturbing trends from the outset and finally failed after 6 days of cycling when the troposphere over Antarctica exhausted. Details of this failure are discussed in NMC Office Note 126 (1976).

Several improvements were made to both the analysis model and the forecast model during the next several months and another 5-day 6-hour cycle experiment was conducted using data from August 1975. Changes made to the models and results of the second test are also documented in NMC Office Note 126. The two most important changes were: (1) an improvement in the way the pole points are treated in the forecast model, and (2) an improvement in the way the analysis model wind law is applied. The forecast model had previously solved the model equations for the pole points, resulting in excessive truncation error. This procedure was replaced by one in which the pole points were obtained as the circumpolar average of the quantities at the adjacent row. The analysis model had previously blended height and wind coefficients. Such a procedure led to an overly strong enforcement of the model wind law and caused the first guess to be altered significantly and adversely in data void areas. The blending was replaced by a method of wind law enforcement which gives increased weight to height data in the wind analysis and wind data in the height analysis, but without blending height coefficients with wind coefficients.

The second test showed the 6-hour cycle to be stable except for two minor problems. The first problem was that occasionally the analysis tropopause finder would fail to find a tropopause and set a default of 70 mbs before smoothing. Such low values of tropopause pressure occurred occasionally over Antarctica and on one occasion led to stratospheric depletion in the subsequent 6-hour forecast. This problem was corrected by placing both upper and lower limiting values on the tropopause which vary with latitude. The second problem was that a large cyclonic vortex developed in the analysis at 1000 mbs under the Himalayan Mountains. This vortex intensified and enlarged with time, eventually producing unrealistic analyses above terrain. Experiments with a one-dimensional (vertical coordinate only) model indicate that cycling with fixed vertical orthogonal functions could lead to such systematic underground intensification in areas of high terrain. The vertical functions represent vertical variation of height, wind, temperature, and relative humidity in the analysis model, and are computed from observational soundings. The problem was corrected by computing a new set of vertical functions every 12 hours from current sounding data, and by introducing subterranean controls on heights and temperatures in areas of high terrain.

A third experiment was then run using data from the same 5-day August 1975 period as the second test. In addition to the changes mentioned above, the following improvements were incorporated: (1) A ninth layer was added to the forecast model (Stackpole, 1976); (2) Initial vertical resolution in the analysis was increased from 2 modes to 4 in order to improve the Southern Hemisphere analyses. Large changes were occurring to the 1000 mb first guess heights in areas where satellite soundings were present, but surface reports were sparse or totally absent. Increased resolution reduces the size of these arbitrary changes but does not solve the real problem which is a lack of sufficient data to adequately define a reference level for satellite sounding data. Such a problem does not exist in the Northern Hemisphere; (3) The temperature toss-out limit was increased slightly to prevent several good temperature soundings from being tossed by the analysis; (4) A new more efficient method for obtaining analysis guess coefficients from global forecast output was implemented. The new method produces essentially the same results as the old but at a cost that is less than 10 percent of the old method.

The third test showed every indication of being stable through 5 days. The configuration of the analysis and forecast models used in this final experiment is what was used in the 6-hour cycle pre-implementation test.

Data Base for 6-Hour Cycle

Prior to implementing the 6-hour cycle test, a program had to be written to provide 6 hourly time-sorted upper-air and surface observation data sets for 00, 06, 12, and 18 GMT. These data sets were generated at final time (H+10) for the 00 and 06 GMT (or the 12 and 18 GMT) periods from the same data base that was available in the NMC 12-hour cycle. This package was put in the production cycle to write these 6-hourly time-sorted files on the NMC final history tape for later use.

Execution of the 6-Hour Cycle

The necessary programs to run the global 6-hour cycle were basically the same as those used in the 12-hour cycle except for some minor modifications to accommodate the use of the 6-hour data files, and the 6-hour forecasts and post-processing. The test was run in parallel to the NMC 12-hour cycle for 10 days covering the period from 12 GMT, August 27 thru 00 GMT, September 6, 1976. The first-guess coefficients for the first case in the 6-hour cycle were identical to the ones used in the 12-hour cycle. Thereafter, the 6-hour analysis system used the first guess from each subsequent 6-hour forecast. All programs were submitted across-the-counter and ran on the OMCS IBM 360/195 computer system with priority=NMCPRI which is just slightly higher than ordinary checkout jobs. Fortunately, we were able to keep up with the 12-hour cycle and completed all jobs on September 6. After that, the big job of evaluation began. A summary of the CPU and wall times for these jobs is shown in Table 1.

Table 1. Summary of CPU and Wall Times for 6-hour cycle pre-implementation test, 10 days (Aug 27 - Sept 6, 1976) run with NMCPRI.

	CPU (min, sec)*			Wall Time (min, sec)*		
	LOW	HIGH	AVG	LOW	HIGH	AVG
STEP NAMES 00/12Z RUN						
DESGLAPP	:11	:13	:12	:52	2:35	1:32
ANLEA	6:01	6:32	6:16	7:16	20:17	11:00
ANLMA	1:33	1:41	1:38	2:30	11:04	4:00
S2G	:44	:48	:46	3:06	7:18	4:46
PACKL3	1:17	1:25	1:20	6:00	22:00	11:00
EXINI	:16	:19	:17	:51	3:27	1:42
ACTIVATE	:01	:02	:01	:47	2:30	1:09
GPEFCST	7:46	8:19	8:00	11:00	23:00	16:00
POSTL3	:15	:18	:16	4:00	16:00	7:00
NEXTGES	:21	:24	:22	:27	1:23	:37
	18:25			37:		
STEP NAMES 06/18Z RUN						
DESGLAPP	:06	:07	:06	:25	1:13	:43
ANLEA	5:07	5:46	5:21	6:40	15:54	10:00
ANLMA	1:19	1:29	1:23	2:05	12:18	4:00
S2G	:43	:49	:45	2:47	8:24	4:38
PACKL3	1:17	1:25	1:20	6:00	18:00	10:00
EXINI	:16	:18	:17	:49	4:58	1:37
ACTIVATE	:01	:02	:01	:43	5:21	1:14
GPEFCST	7:44	8:06	8:00	10:00	24:00	15:00
POSTL3	:14	:17	:15	4:00	11:00	6:00
NEXTGES	:20	:21	:20	:25	1:28	:37
	17:07			34:		

NMCPRI is an OMCS priority, slightly higher than checkout.

* Some large values have been rounded to nearest minute.

Description of Step Names used in Table 1.

Step Name	Job Description
DESGLAPP	Re-formats upper-air and surface data for input to Flattery analysis program
ANLEA	Flattery analysis of heights and winds
ANLMA	Flattery analysis of temperature and humidity
S2G	Transformation of analyses in spectral form to hemispheric grid form (2.5 latitude/longitude)
PACKL3	Processor to create Level III archive file and a special file for input to VARIAN display program
EXINI	9L-PE initialization program
ACTIVATE/GPEFCST	9L-PE forecast program (6 hours)
POSTL3	Processor to form forecast Level III fields for archive
NEXTGES	Program to calculate first guess coefficients from forecasts—used in next cycle

Evaluation of Surface Pressure Tendencies and Model Stability

In previous experiments with the 6-hour cycle, conducted first in the May 1974 DST, later by Rasch and McPherson (1975), and again in June 1976, the RMS surface pressure tendency of the forecast model was used to measure the noise level of the forecast model. This measure was carefully monitored during the test of the 6-hour cycle and results are shown in Fig. 1. The maxima, which occur in the first hour of the forecast, remain below .4 mb/hr and the curve becomes asynoptic at hour 5, at a level near .1 mb/hr. These tendency values are slightly lower than in the preceding tests and demonstrate greater stability with less noise accumulating early in the forecast. As stated in the earlier draft evaluation, this stability is due to the increase in vertical resolution, from 8 layers to 9 layers, in the prediction model.

Kinetic Energy Comparisons (Forecasts)

As an additional measure of the 6-hour cycle prediction model performance, we decided to use the total forecast kinetic energy. Experience suggested that the 6th layer (just below the model tropopause) might better show any differences between the 6- and 12-hour cycles. We had some experience with energy changes in the 12-hour forecast and Fig. 2 shows that the current 12-hour cycle behaved predictably (small differences between hour 12 and the subsequent initialization level, with the maxima occurring at hour 9). The 6-hour pattern differs noticeably (Fig. 3) with more abrupt rises in energy during the first 6 hours. Another significant difference is in the more extreme drop from the hour 6 forecast energy level from a 00 GMT or 12 GMT to the subsequent 06 GMT or 18 GMT initialization level. These differences are a result of the additional initialization (with the attendent truncation and the loss of the divergent portion of the wind) aggravated by greatly reduced numbers of upper-air reports. A small portion of the difference may result from the model's tendency to lose eddy available potential energy during the initialization to and conversion from forecast model layers and pressure levels. An example of upper-air data coverage in the 6- and 12-hour cycles can be seen in Figs. 5 and 7, respectively.

Data Counts and Coverages

Upper-air data distributions at selected levels within 12-hour and 6-hour time blocks are contained in Fig. 4. The variation by time in the 6-hour data distribution is due to an economic decision made some time ago by the United States and Canada to provide upper-air soundings only every 12 hours (at 00Z and 12Z). However some countries in Europe and the USSR, and Australia and New Zealand do provide 06 and/or 18 GMT upper air reports. No attempt was made to graph surface data counts as these are fairly uniform at each 6-hourly observation time.

The areal non-uniformity of upper-air data coverage in the 6-hour cycle is shown in Figs. 5, 6, and 8. Great sparsity of upper-air observations over large land masses and over some ocean areas is noted at 06 and 18 GMT (Fig. 5b and d) in the Northern Hemisphere. When the 24-hour coverage in the Southern Hemisphere is examined (Fig. 6a - d) the dependence on satellite data in the analysis cycle becomes quite obvious. At the present no NESS cloud track winds are available at 06 and 18 GMT but NESS does plan to provide these data at a later date. The aircraft wind data are fairly evenly distributed in time; however, few reports are received from the Southern Hemisphere of the total available (personal communication from Mr. R. L. Southern, Director, Western Region, Australian Meteorological Service). Surface data is much more evenly distributed throughout the four daily synoptic observation times (see Figs. 7 and 8). Ship surface reports tend to be fewest in the Atlantic at 06 GMT and in the Pacific at 18 GMT. Fewer Southern Hemisphere land reports are noted over South Africa at 00 GMT (Fig. 8a) and South America at 06 GMT (Fig. 8b). This reflects an overall minima of nighttime surface data (near local midnight). Ship surface reports are few and widely scattered in the Southern Hemisphere. It is noted that the 6-hour cycle has the benefit of the additional 6-hourly update of surface data at 06 and 18 GMT and with almost the same coverage. This resulted in fewer surface reports being rejected by the analyses and in a better reference level for satellite reports.

Data Fits in the Analyses

The average RMS differences of the data (height and wind) in the analyses at 00 and 12 GMT of the 6- and 12-hour cycles are shown in Table 2. The RMS differences in both cycles are large after iteration 1 of the Flattery analysis because the initial throw criteria are large (914 m height and 120 kts vector error at all levels). The throw criteria after 9 iterations drops to 40 m height (ZE) and 24 kts vector error (VE) at 1000 mb, and to 107 m height and 42 kts vector error at 300 mb. The only difference between the 6-hour and 12-hour cycles is in the time span of the upper-air data. The 12-hour cycle uses data $\pm$ 6 hours of the analysis time through 5 iterations and reduces the time span to $\pm$ 3 hours throughout the 9 iterations of the analysis. Table 2 shows a marked reduction in the RMS fit errors for both cycles thru 9 iterations, but the 6-hour cycle differences are generally smaller at completion. The averages do not include the RMS values from the 06 and 18 GMT analyses when somewhat more variability is noted.

Table 2. Comparison of average RMS fit of data to the Flattery analyses at selected levels at 00Z and 12Z during the 6-hour cycle experiment.

	SCAN	850MB 6HR	850MB 12HR	500MB 6HR	500MB 12HR	300MB 6HR	300MB 12HR	100MB 6HR	100MB 12HR
RAOB	1	55.4M	57.6	49.7	50.6	61.8	60.7	76.4	76.5
RMSZE	9	11.0	11.5	15.7	16.6	25.8	26.8	43.3	45.6
VTPR	1	13.6M	13.5	38.6	38.8	56.4	57.7	58.2	61.0
RMSZE	9	8.2	8.6	17.1	18.7	26.8	28.4	29.7	31.9
RAWIN	1	12.4KT	12.3	15.5	15.6	23.5	23.8	12.8	13.0
RMSVE	9	8.5	8.6	8.7	8.8	12.3	12.5	6.3	6.6
NESS WIND	1	14.7KT	10.9	19.2	19.0	27.4	27.4	*28.1	*28.9
RMSVE	9	7.6	7.1	9.2	9.9	14.5	15.3	11.5	12.1
ACFT WIND	1	11.0KT	13.2	15.8	16.7	23.1	25.6	*18.3	*22.6
RMSVE	9	9.8	10.4	10.2	10.2	14.3	14.7	8.6	12.0

* At 150 MB

Forecast Verifications and First Guesses

RMS forecast errors were calculated for the 6- and 12-hour cycles from a network of 80 upper-air reporting stations (Fig. 10). The forecasts are from the 9-layer model and are used to create the "first guess" for the subsequent analysis. The RMS speed errors (SE) and vector errors (VE) at selected levels for the 6- and 12-hour cycles are shown in Fig. 11. Note that the differences are small.

The RMS height (ZE) and temperature error (TE) are graphed on Fig. 12. The significant difference in height error (Fig. 12a) is in the lowest level (850 mb) where the 6-hour cycle error averages 2 meters lower as the result of the 6-hour update with surface data. Above the 850 mb level the difference in error is more random, and on the average no advantage appears in either cycle.

The temperature differences (RMS TE) in Fig. 12b are most noticeably large at the lowest level (850 mb). The sharp increases in the forecast temperature error at 850 mb of the 6-hour cycle at 12 GMT (approximately .8°C in the average), followed by an equally sharp decrease in error at 00 GMT, result from the influence of the surface temperature analysis at 06 or 18 GMT on the temperature fields in lower layers[1]. The verification network covers an area which has relatively few upper-air reports at 06 and 18 GMT to control the diurnal surface temperature effect. The error at the 850 mb appears to be reflected at the 300 mb level but is less definite.

In order to identify the bias of the temperature and height errors, the algebraic mean errors are shown on Fig. 13. The mean height error ($\overline{ZE}$ of Fig. 13a) shows a negative height bias in both cycles, but the average differences are quite small. The 850 mb mean temperature error ($\overline{TE}$ of Fig. 13b) identifies a strong negative bias (-.96°C) of the 6-hour cycle at 12 GMT. This bias at 00 GMT becomes +.16°C. This curve shows the diurnal effect of the surface temperatures on the forecast. The 6-hour mean forecast temperature error ($\overline{TE}$) at 300 mbs has a positive bias (+1.36) at 12 GMT, and has a negative correlation with the low level temperature error.

Energy Comparisons (Analyses)

Latitudinal energy calculations from the 6- and 12-hour cycle analyses were made over the Northern and Southern Hemispheres to quantify differences noted in the comparative height and wind fields. The largest analysis differences in the two cycles appeared at the 300 mb level, and corresponding energies for that level are shown on Fig. 14. In the Northern Hemisphere (0° - 90° lat.) almost no differences can be distinguished (Fig. 14c) between the average zonal kinetic (KZ) curves and the average eddy kinetic (KE) energy curves for the two cycles. In the tropics (20°N - 20°S lat.) the general levels of

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[1] The excess temperature errors of the 6-hour cycle have been eliminated by a revision to the 9-layer initilization code.

both the zonal kinetic and the eddy kinetic energies (Fig. 14b) are lower in the 6-hour cycle. The energy levels vary noticeably in the Southern Hemisphere (0° - 90°S, Fig. 14a), and are about 8% lower in the 6-hour cycle. These differences are further shown by comparing the 6- and 12-hour cycle cross-sections (Figs. 15 and 16) of eddy kinetic and zonal kinetic energies. The cross-sections also show the reduction in eddy kinetic energy maxima at the jet stream level (near 250 mb). The reason for these differences is not clear, but a relationship must exist between the presence of satellite (VTPR) data and the change of kinetic energy in the Southern Hemisphere.

The zonal averages of U, V, Z, and T for 12 levels (1000 to 50 mb) and RH (1000 to 300 mb) from North to South Pole were critically examined for the 10-day test period. Only very small differences were noted between cycles in the U-components (1 to 2 kts), and those were in the Southern Hemisphere in the vicinity of the jet stream. The average global differences between the two cycles in the height and temperature fields were almost zero except near the South Pole at levels above 9 km where the 12-hour cycle had colder temperatures and lower heights. The relative humidity comparisons showed random differences in the mid-troposphere of both hemispheres.

Harmonic Analyses

Harmonic analysis of U, V, Z and T at 850 and 300 mb were performed on the Flattery analysis of 00Z 29 Aug 1976. This case is examined as one of many showing a reduction in energy of the 6-hour cycle. The program produces zonal means, total variance (σ^2), the amplitudes of the first 24 harmonics and their relative variances of the selected parameters in 5° latitude circles. The variances of the parameters were examined for the Northern Hemisphere and were found to be almost identical; the largest differences were noted in the temperature variances at 300 mb and 850 mb (Fig. 17), but are not considered significant.

The graph of Southern Hemisphere 850 mb temperature variance (Fig. 18a) does show significant differences between 55° and 80°S latitude. The harmonics of the 850 mb temperature at 55°S (Fig. 18b) show a shift from a dominance in waves 5-8 in the 12-hour cycle to waves 4-6 (synoptic scale). This latitude 55°S is the center of the latitude band (45° - 65°S) in which there is greatest areal density of satellite data in the 12-hour cycle. The observation times cover ± 6 hours and data at the extremes of this time span may be within 400 km of each other. The effect of the 6-hour cycle is to reduce this time variability and therefore some of the variance. The 6-hour update also allows the surface reports from island and Antarctic stations at these latitudes to be used more effectively.

The variances of the 300 mb U, V and Z in the Southern Hemisphere of the 6- and 12-hour cycles are quite similar, but the amplitudes of the 12-hour cycle are greater. The Southern Hemisphere 300 mb temperature variance (Fig. 19a) shows a strong shift from a maxima at 40°S of the 6-hour analysis to a larger maxima at 60°S of the 12-hour analysis (again right on the edge of the area of maximum influence of off-time VTPR). At this level at 55°S, (Fig. 19b) the temperature harmonic amplitudes of the 6-hour cycle show relative maxima in waves 1-3 and waves 6-8.

Subjective Analysis Differences

The analyses of the height, temperature and wind fields, at five representative mandatory levels at 00 and 12 GMT, were monitored during the 6-hour experiment and were compared with those from the 12-hour cycle. In the Northern Hemisphere the analysis differences were quite small and could be explained as the result of the additional analyses of 06 and 18 GMT reports. However, the differences in the Southern Hemisphere are much larger and can be explained, in part, by the additional 06 and 18 GMT analyses and, more so, by the distribution of VTPR data.

The largest differences consistently occur to the southeast of Africa in the South Indian Ocean (an area with abundant VTPR but few RAOB soundings). For an example the 1000 mb and 300 mb height and temperature analyses from the 12-hour and 6-hour cycles of 00Z 29 Aug 76 are shown in Fig. 20 through 23. The differences of the forecasts used to produce the first guesses to the analyses are shown in Figs. 20-23c. The analysis differences of the 6- and 12-hour cycles are shown in Figs. 20-23d.

The 12-hour cycle 1000 mb height analysis lacks the amplitude of the 6-hour cycle (Fig. 20a and b) and the 1000 mb temperature analyses reflect a similar problem (Fig. 21a and b). The 12-hour temperature analysis lacks the organized gradients of the 6-hour cycle. This can be confirmed by comparing the analyses with the NOAA-4 IR mosaics (not shown) closest to synoptic time. These differences are tied to the 6-hour update which improves the use of the few conventional reports available in sparse data regions (fewer reports are tossed by the analysis). At 300 mb, substantial height and temperature differences are noted between the two forecasts valid at 00 GMT, August 29 (Figs. 22c and 23c). Available data were then used in the 6-hour and 12-hour cycle analyses at 00 GMT. The differences between the two analyses at 300 mb are shown in Figs. 22d and 23d. Note that the height differences in the analyses are even greater to the southeast of Africa than those described by the corresponding forecast differences--right in the area where the off-time VTPR were used in the 12-hour cycle! In the region between 40° and 60°S, 40° and 80°E, there are a great number of off-time VTPR reports (03 to 05 GMT) which were analyzed in the 12-hour cycle as synoptic. This, coupled with the differences noted in the 1000 mb reference level, produced large differences in the 12-hour cycle 300 mb height analysis. The net result was the advancement of the upper-level trough (in the 12-hour cycle) to a position over the surface wave which then lost thickness support for the front identified on the satellite pictures. Figure 24 shows the upper-air data positions for the

12-hour analysis and the limited few data positions (designed by dots) available to the 6-hour analysis. The squares represent the positions of VTPR in the period between 0301 and 0600 GMT. It is that distribution which produced the largest change to the 12-hour cycle analysis and resulted in the loss of frontal definition which the 6-hour cycle retained. The approximate frontal positions at the times indicated are shown as dashed lines and were interpreted from the NOAA-4 cloud mosaics.

Another factor noted south of Africa is the flattening of the 1000 mb height and temperature gradients in the region of numerous off-time VTPR reports. Figure 25 is the RAOB sounding (solid lines) for Marion Island (46.9°S, 37.9°E), which is located west of the frontal position on Fig. 24. Shown, also, are two VTPR soundings: one at 1800Z (dashed line) is prefrontal and; the other at 0501Z (dotted) is postfrontal. The 12-hour cycle had both of these VTPR and the RAOB in the 00Z 29 Aug 76 analysis, but the 6-hour had only the RAOB. The reported 1000 mb height was 207 m at Marion, but because of first guess differences (the 12-hour cycle being 100 m low) the low level RAOB heights were modified downward in the 12-hour cycle.

The analysis of the off-time VTPR to the west of the frontal zone in the 12-hour cycle resulted in even more loss of detail. The 1000 mb height at 0501Z's position (reference Figs. 24 and 25) was analyzed as 90 m on the 12-hour cycle (vs 170 m on the 6-hour which had only the RAOB and the 6-hour update). At the position of the 1800Z VTPR report the analyzed height was 120 m (vs 185 m on the 6-hour cycle). The 12-hour cycle first guess expected a 103 m 1000 mb height, so that Marion Island's low level RAOB height exceeded the throw criteria. The 6-hour first guess was updated at 28/1800Z and no data in that area were thrown on the 6-hour cycle analysis at 18Z. This only serves to point out the desirability of the 6-hour update where the atmosphere is changing and should result in an improved reference level for the satellite data in the Southern Hemisphere.

6L PE Forecasts

The 6-hour cycle test was run for 10 days (12Z, 27 Aug 76 to 00Z, 6 Sept 76). We chose three days out of this test period and generated 12 hour through 84 hour forecasts for the Northern Hemisphere with the 6-layer PE model.

The following items were considered in determining suitable initial conditions for a forecast run:

1. Analysis differences in the height fields at 1000 mb and 300 mb between the 6-hour cycle and 12-hour cycle

A look at Fig. 26 through 31 shows that analysis height differences between the two cycles were generally small. At 1000 mb, height differences were mostly less than 30 m, while at 300 mb 30m centers are observed in a very few limited areas. The figures are fairly representative for the entire test period.

2. Forecast differences between the 6-hour cycle and the 12-hour cycle first guess 1000 mb and 300 mb height and temperature forecasts (6-hour and 12-hour forecasts, respectively)

Large differences did show up between these forecasts during the entire test period. The large differences are mostly the result of the introduction of new surface data at 06Z and 18Z; data that was not available to the 12-hour cycle (see Fig. 32 to Fig. 37). In absence of any significant analysis differences these forecast differences were mostly used to select the forecast days for the test.

3. Intensity of the large scale upper level circulation

Most of the activity in the Northern Hemisphere circulation was north of 40°N during the test. While no major storms were observed at sea level (except for 2 seasonal hurricanes in the Atlantic), or intense cyclogenesis was taking place, the upper air circulation was by no means stagnant. During the test period the long wave pattern in the Northern Hemisphere had substantial amplitude with some vigorous short wave activity. The forecast days were chosen to take into account the onset and development of various long wave and short wave systems. The development at 1000 mb was used only as a secondary guide.

4. Verification area

The area under consideration for verification was limited to an area between 160°W and 20°E which includes the eastern Pacific, North America, the North Atlantic and Europe.

<u>Comparisons of 6L PE Forecasts</u>

The 6L PE forecasts based on the 6-hour cycle were compared with the NMC's 6L PE operational forecasts. In evaluating the results of this comparison we should keep in mind that the operational forecasts are based on data with a 4-hour cut-off time, while the 6-hour cycle forecasts were run with a 10-hour data cut-off. Another fact that could affect the results is the non-divergent start of the 6-hour cycle forecasts.

The objective of the forecast comparisons was to show that forecasts generated from a 6-hour cycle analysis/forecast system were as good as or better than the forecasts derived from a 12-hour cycle system.

A look at Table 3 reveals immediately that the RMS forecast differences involved are rather small. The table depicts the root-mean-square height differences at 1000 mb and 500 mb for the total 65x65 6L PE grid between the 6-hour cycle and 12-hour cycle forecasts. It is also apparent that there is very little growth in the forecast differences with increasing forecast time.

Table 3. Root-Mean-Square Differences Between 6-Hour Cycle and 12-Hour Cycle Forecasts

1000 MBS

	0	12	24	36	48	60	72	84
00Z 28 Aug 76	7.13	13.45	12.05	12.43	12.44	11.14	14.22	13.13
00Z 30 Aug 76	9.60	12.66	12.81	12.73	13.58	12.98	13.37	14.04
00Z 1 Sep 76	8.86	12.43	12.16	12.63	12.22	12.94	12.88	12.65

500 MBS

	0	12	24	36	48	60	72	84
00Z 28 Aug 76	10.59	13.30	11.41	10.95	12.05	11.17	13.43	13.47
00Z 30 Aug 76	12.66	10.73	11.08	9.38	11.87	11.52	11.86	13.38
00Z 1 Sep 76	10.58	11.77	10.80	10.94	10.81	11.08	11.99	13.66

Evaluation Considerations of 6L PE Forecasts

For a more detailed evaluation of these forecast differences the following forecast verifications were performed:

1. Verification against observations

Eighty radiosonde stations over North America, Western Europe and fixed ocean vessels were used in this verification. Forecast heights, temperatures and winds were compared with the radiosonde observations valid at forecast verifying time. See Fig. 10 for the location of the radiosonde stations. The statistics calculated were mean errors, absolute errors, root-mean-square errors and for the winds the vector and speed errors.

The precipitation verification was limited to the calculation of the threat score for NMC's 60 station network (see Fig. 38). Although this type of verification provides us only with a spot check of the precipitation forecasts, it was considered adequate for the purpose of distinguishing major discrepancies in the precipitation forecasts of the two cycles.

2. Verification of forecasts against analyses

The verifying analyses used were NMC's final analyses. Differences between 6-hour cycle and 12-hour cycle analyses were small and it would have made little difference if either analysis was used. The only statistic calculated from this verification was the S1 score for the forecast height fields over the United States and over Europe. The grid used is shown in Fig. 39.

3. A subjective evaluation of the various forecasts

We looked at all forecast cases and studied all forecast periods. Special attention was given to the development of pressure systems at the 1000 mb level and the long wave patterns at the 500 mb level. The evaluation consisted out of a visual comparison between the forecast maps of the 6-hour cycle and those of the 12-hour cycle. In addition, each forecast was compared with its verifying analysis.

Discussion of 6L PE Forecast Verification Results

The root-mean-square forecast height errors at 1000 mb and 500 mb for the three forecast cases are shown in Fig. 40a. We note, first of all, that the differences between the cycles are rather small and, secondly, that the 6-hour cycle consistently shows a slight superiority over the 12-hour cycle. A similar pattern is noted in the wind error statistics (see Fig. 40b).

If there were any significant forecast differences these should certainly show up in the longer forecast periods. A look at the 72-hour root-mean-square errors in height, temperature and wind at various levels show these differences to be rather small with the 6-hour cycle again having somewhat lower errors than the 12-hour cycle.

S1 scores were calculated for the North American grid and European grid and the results have been tabulated in Tables 4 and 5.

The S1 scores for both areas show that the 6-hour cycle forecast from 00Z, 28 August 76 and from 00Z, 1 September 76 were generally better than the 12-hour cycle forecasts. The 00Z, 30 August 76 show few and small differences in skill between both cycles, while over Europe the 12-hour cycle seems to have the edge over the 6-hour cycle.

The greatest differences in skill are observed in the 00Z, 1 September 76 case. The 6-hour cycle forecasts beyond 48 hours are much better than the forecasts of the 12-hour cycle. This is especially true for the 500 mb forecasts over both North America and Europe.

During the subjective evaluation of the individual forecast cases it became quite apparent that the 6-hour cycle showed a better definition and timing of the progression of the shorter waves resulting in a gradient distribution that was closer to what was observed at verifying time.

A discussion of the 00Z, 1 September 76 case (see Figs. 41-55) can serve as an illustration of this observation. For brevity, we will limit our discussion to the development at 500 mb.

During the forecast period that starts at 00Z, 1 September and ends 12Z, 4 September 76, zonal flow reestablishes at 500 mb over the eastern Pacific and North America as the central Pacific trough moves eastward and the trough off North America fills and moves inland. Similarly the Great Lakes trough fills and moves northeastward.

In the early forecast periods only minor differences are noticeable. Beyond 48 hours the 500 mb height differences between the two cycles are large and by 72 hours centers with 30 m differences are located over the Northern Plain States, the Great Lakes and Newfoundland.

These differences are due to the handling of the shorter waves in the westerlies. Note: e.g., the impulse in the westerlies over Manitoba. This wave is less intense and somewhat faster in the 6-hour cycle than in the 12-hour cycle. The resulting 72-hour forecast from the 6-hour cycle is definitely much better than the 72-hour forecast of the 12-hour cycle. The S1 scores and the verification against radiosonde stations do bear this out (see Figs. 56-60).

Table 4. S1 Score comparison between the 6-hour cycle and the 12-hour cycle for the 1000 mb and 500 mb level for Area I (United States). S1 - Score difference between cycles given by (12HR-6HR).

1000 MBS		FORECAST PERIOD						
INITIAL DATE		12	24	36	48	60	72	84
00Z, 28 AUG 76	6HR CY	44 (-2)	64 (+5)	74 (+2)	83 (+1)	-	91 (-1)	81 (+2)
	12HR CY	42	69	76	84	-	90	83
00Z, 30 AUG 76	6HR CY	-	58 (0)	69 (-2)	66 (+2)	74 (0)	76 (-1)	84 (-4)
	12HR CY	-	58	67	68	74	75	80
00Z, 1 SEP 76	6HR CY	55 (+3)	58 (+6)	60 (+2)	62 (+2)	68 (+5)	78 (+3)	84 (+6)
	12HR CY	58	64	62	64	73	81	90

500 MBS		FORECAST PERIOD						
INITIAL DATE		12	24	36	48	60	72	84
00Z, 28 AUG 76	6HR CY	26 (+1)	35 (+1)	40 (+4)	49 (+2)	-	52 (+3)	49 (+4)
	12HR CY	27	36	44	51	-	55	53
00Z, 30 AUG 76	6HR CY	-	34 (-1)	44 (-2)	45 (-2)	43 (0)	48 (0)	60 (0)
	12HR CY	-	33	41	43	43	48	60
00Z, 1 SEP 76	6HR CY	26 (+5)	25 (+2)	32 (+2)	40 (+1)	48 (+4)	55 (+7)	56 (+9)
	12HR CY	31	27	34	41	52	62	65

TABLE 5. S1 Score comparison between the 6-hr cycle and the 12-hr cycle for the 1000 mb and 500 mb level for Area III (Europe). S1 - Score difference between cycles given by (12HR-6HR).

1000 MBS		FORECAST PERIOD						
		12	24	36	48	60	72	84
INITIAL DATE								
00Z, 28 AUG 76	6HR CY	33 (-2)	38 (+6)	43 (+2)	56 (+3)	-	79 (+1)	77 (0)
	12HR CY	31	44	45	59	-	80	77
00Z, 30 AUG 76	6HR CY	-	43 (+2)	49 (-1)	52 (0)	55 (0)	60 (-1)	68 (-5)
	12HR CY	-	45	48	52	55	59	63
00Z, 1 SEP 76	6HR CY	33 (+6)	46 (+2)	52 (-1)	50 (0)	59 (-6)	62 (+7)	66 (+3)
	12HR CY	39	48	51	50	65	69	69

500 MBS		FORECAST PERIOD						
		12	24	36	48	60	72	84
INITIAL DATE								
00Z, 28 AUG 76	6HR CY	23 (+1)	28 (+2)	40 (+2)	45 (+2)	-	54 (+3)	63 (+2)
	12HR CY	24	30	42	47	-	57	65
00Z, 30 AUG 76	6HR CY	-	29 (-1)	34 (-2)	34 (-2)	36 (-2)	43 (-3)	50 (-4)
	12HR CY	-	28	32	32	34	40	46
00Z, 1 SEP 76	6HR CY	23 (+1)	33 (+1)	38 (0)	42 (0)	47 (+2)	50 (+3)	54 (+6)
	12HR CY	24	34	38	42	49	53	60

Over Europe a closer look at the individual forecast maps reveal differences that might explain the better S1 scores of the 6-hour cycle. From 48 to 72 hours the 6-hour cycle forecasts show a strengthening of the gradient in the trough over the North Sea and Scandinavia, more so than the 12-hour cycle. However, over continental western Europe the 6-hour cycle forecast gradient is less than on the 12-hour cycle.

A comparison of the gradient distribution of the observed map with the 72 hour forecasts of both cycles shows that 6-hour cycle forecast is better than that of the 12-hour cycle.

The RMS height errors (see Fig. 58) are quite large by 72 hours, reflecting in part the slowness of the forecast trough position. Here again the 6-hour cycle forecast looks better than the 12-hour cycle in the verification against observations.

6L PE Forecast Precipitation Verifications

Precipitation threat scores are presented in Table 6. The non-divergent start of the 6-hour cycle may account for the larger threat scores of the 12-hour cycle than the 6-hour cycle. Since the 60 station network is rather coarse, the threat scores amount to only a spot check of the precipitation forecasts. Overall the 12-hour cycle forecasts seem to have better threat scores.

Conclusions and Recommendations

The 6-hour cycle has advantages in that the upper-air data are treated more synoptically and the numerous 06 and 18 GMT surface observations can finally get into the NMC analysis/forecast system. The 6-hour cycle also produced better data-fit RMS statistics as compared to the corresponding 12-hour cycle analyses.

The most important improvement over the 12-hour cycle was the effect of the 6-hour update in sparse data regions. This was particularly true over areas where systems were changing rapidly. The 6-hour cycle allowed for more accurate low-level analyses by incorporating smaller changes as opposed to one large (12-hour) change as a system moved into the vicinity of an isolated report. Because of the lack of surface data in some oceanic areas, most definite in the Southern Hemisphere, a need exists for additional surface information in the form of bogus reports to better define the reference level for satellite soundings.[2] These bogus reports could be based on satellite cloud pictures and continuity considerations from the manually analyzed surface (MSL) charts.

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[2]Bogus reports were introduced in the Southern Hemisphere for a 12-day period of the Data Systems Test (DST-6) between February 17 and March 1, 1976, by David Wright, Australian Meteorological Service, and the quality of the analyses was greatly improved.

TABLE 6. Comparisons of precipitation threat scores for 60 U.S. stations network for the 6-hr cycle and 12-hr cycle.

		FORECAST PERIOD						
		12	24	36	48	60	72	84
INITIAL DATE								
00Z, 28 AUG 76	6HR CY	.18*	.19	.18	.21	.18	.10*	0
	12HR CY	.10	.23*	.27*	.25*	.18	.17	.09*
00Z, 30 AUG 76	6HR CY	.30*	0	0	.19	.16	.35*	.30
	12HR CY	.14	.11*	0	.21*	.20*	.25	.30
00Z, 1 SEP 76	6HR CY	.26*	.24	.38	.05	.07	.09	.13*
	12HR CY	.21	.43*	.59*	.20*	.20*	.09	.10

* This indicates a better forecast.

The lower kinetic energy levels of the 6-hour cycle analyses may be a problem and should be identified more precisely. A portion of the energy loss may be related to the forecast model to some extent, but may also be related to the additional 06 and 18 GMT analyses which have fewer upper-air reports. The energy loss may also be more important in the winter hemisphere because of the conversion of available potential to kinetic energy which dominates at that time.

The available potential energies determined from the 6-hour forecasts were usually at a lower level than the potential energies determined from the analyses used for each forecast. This apparent loss of energy may be the result of the model's initialization procedure (converting from pressure to sigma coordinates). This problem probably needs further investigation.

The test was limited and 3 forecast cases do not allow us to draw any rigid conclusions. However, the statistical and subjective evaluations show a positive impact of the 6-hour cycle on the forecasts generated from this cycle as compared to the forecasts generated from the 12-hour cycle. For the verifications against observations, the results for the total 80 station sample, or for the North American and European subset, show RMS errors for the 6-hour cycle less or very little different from the 12-hour cycle.

In two cases the S1 scores for the 6-hour cycle forecast are mostly better over North America and Europe. In the subjective evaluation of the forecasts for both cycles the 6-hour cycle seems to have a better way of handling the shorter waves which contributed to better 6-hour cycle forecasts. The information gained from the precipitation verification of both cycles is sketchy and no firm conclusions can be drawn from this sample.

Overall, we conclude that the 6-hour cycle is stable. We also recommend that the 6-hour cycle be considered as a replacement to the present 12-hour "final" cycle in the NMC production runs.

Implementation Considerations/Requirements for 6-Hour Cycle Observational Data Files

Observational data will have to be prepared in 6-hour time sorts. Some files are currently available for 6-hour time sorts of conventional surface and upper-air reports, but additional files will have to be created for 6-hour sorts of SIRSOB, and maybe SATWND and AIRCFT data files, which are now 12-hour sorts (± 6). A capability now exists to activate the UPAMAN file, via the Sander's Scope, which contains a list of bad reports that should not be used in the analysis system. Considerations should be made to have four distinct UPAMAN files for 00, 06, 12, and 18 GMT, rather than the current two files for 00 and 12 GMT. For example, during the 06 GMT analysis, any deletes scheduled to be honored for bad VTPR data during the period 03 - 06 GMT would be contained in the 00 GMT UPAMAN file; however, the delete information covering the period 06 - 09 GMT would have to be found in the subsequent 12 GMT UPAMAN file, which depending on the time that the 06 GMT analysis was scheduled to be done, may not be ready for use.

On-Line Disk Space

Additional on-line disk space will have to be provided to keep the off-time (06 and 18 GMT) guess and analysis coefficients, gridded analyses and forecasts, and sigma history data (as required). These data sets will eventually be copied to an appropriate archive (history) tape. The disk space requirements for these off-time files are identical to those currently being used in the 12-hour cycle.

Archive (History) Tape

The current NMC history tape for the "final" run will have to be modified to allow for saving all of the 6-hour time-sorted observational data files, the guess and analysis coefficients, selected gridded analysis and forecast fields, and possibly the sigma history files for each 6-hour cycle. There is sufficient space on a 2400-foot magnetic tape to accommodate these history files for two 6-hour cycles; separate history tapes for each cycle would only increase tape handling procedures. For separation, all of the history data for the 00 GMT run could be contained in the first physical file on tape, and the 06 GMT run history data could be written as a second physical file on the tape. Similarly, the 12 and 18 GMT runs could be saved on another archive tape. If unique NMC O.N. 85 logical file names are available, all the necessary files for a 00 and 06 GMT run could be combined into one physical file on the history tape.

Code Changes in Production Cycle

If the observational data files are provided in 6-hour time sorts, the current global analysis pre-processor (GLAPP) program and its JCL would more than likely remain the same--the pointers to the necessary files are controlled with a PROC (a procedure). If special data files have to be generated to accommodate 6-hour time sorts, similar to what was done in this test, then some modifications to GLAPP will be necessary. (GLAPP is designed to match specific logical file names within the code.)

A minor change may have to be made in the forecast code to output the 6-hour forecast data which is used to provide the first guess for the subsequent cycle. This load module currently exists. The data card deck used to control the forecast code will also have to be modified--a relatively simple change.

The JCL pertaining to all jobs associated with the Flattery analysis codes, the spectral-to-grid transformation code, the 9-L initialization and forecast codes, the post-processor code, and the code to generate the guess coefficients for the next cycle will have to be modified to use appropriate input/output file names. Some of these files will be the newly-created files mentioned above for the off-time 06 and 18 GMT runs; files currently used for 00 and 12 GMT runs in the 12-hour cycle will still be utilized, as necessary.

The current Network used to control the "final" production jobs will have to be modified to control two 6-hour cycles.

The "final" archive job will have to be modified to provide for saving two 6-hour cycle runs on the history tape. This may be accomplished by changing the PROC and associated JCL currently being used.

The CPU and wall times necessary to complete two 6-hour cycles in the NMC production mode should be less than or equal to the low times indicated in Table 1. For the pre-implementation test, the best CPU time (sum) of two consecutive cycles was about 35.5 minutes, and the total wall time was about 111 minutes. The production versions of these codes should require less time, depending on the amount of processing required for graphical displays.

Acknowledgments

We wish to express our appreciation to Carl Amorose and Eugene Brown for their contributions in running the various programs, tabulating results, and drafting some of the figures; to Barbara Boyd for typing the report and the various tables; and to Andy Caporaso for copying the necessary NMC operational and final history tapes.

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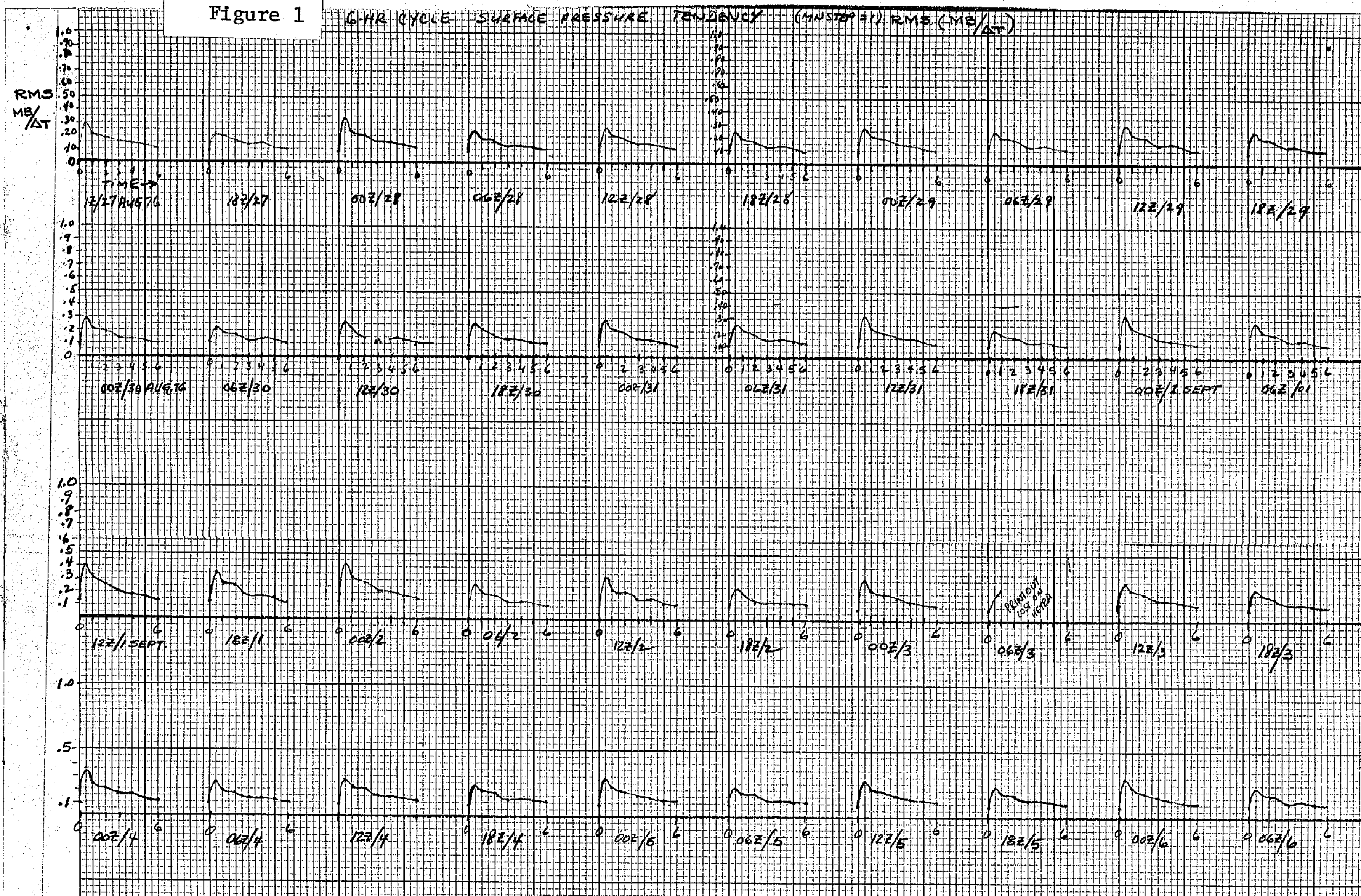
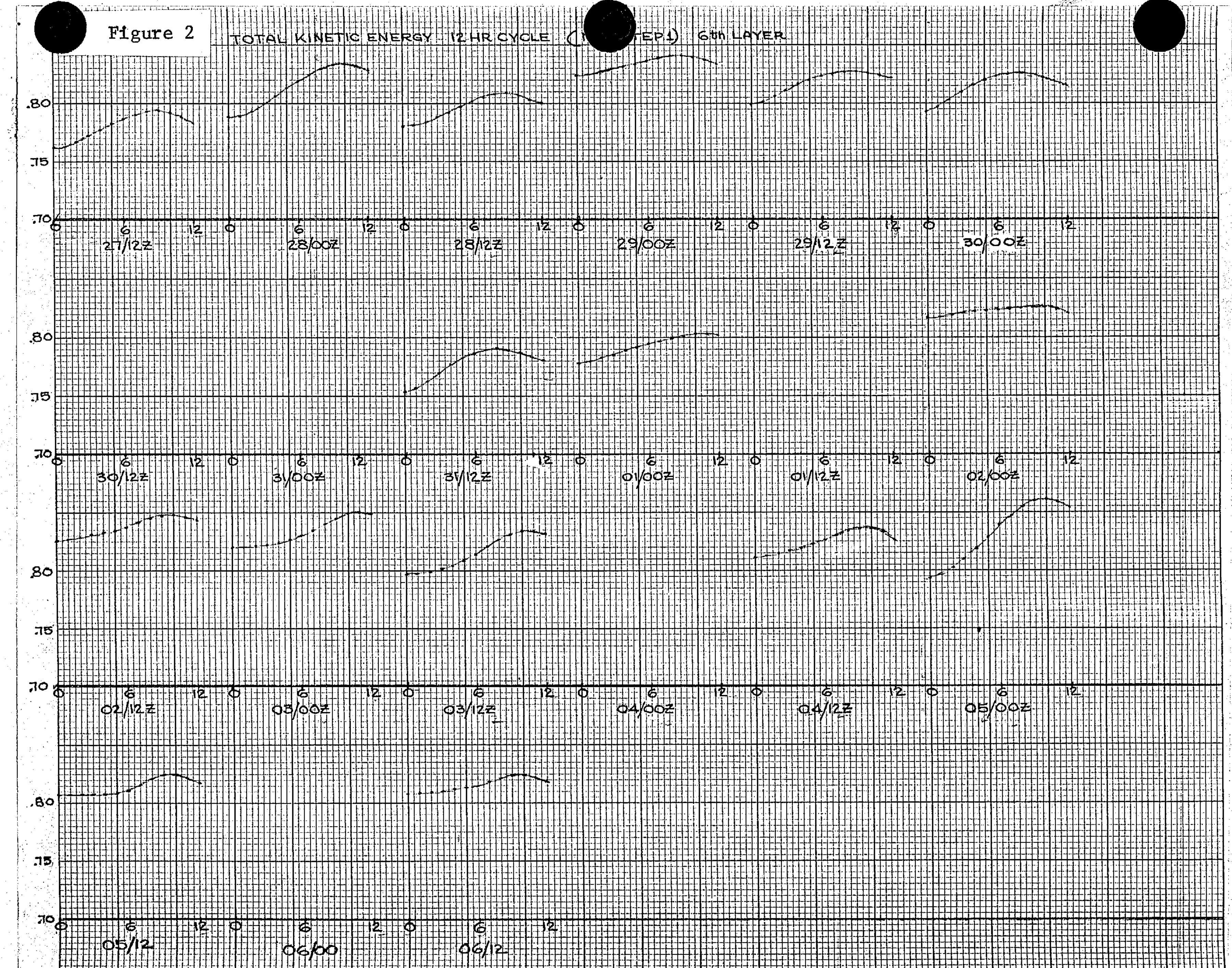

6 HR CYCLE SURFACE PRESSURE TENDENCY (MNSTEP=1) RMS (MB/ΔT)
RMS MB/ΔT
TIME→
12Z/27 AUG 76
18Z/27
00Z/28
06Z/28
12Z/28
18Z/28
00Z/29
06Z/29
12Z/29
18Z/29
00Z/30 AUG 76
06Z/30
12Z/30
18Z/30
00Z/31
06Z/31
12Z/31
18Z/31
00Z/1 SEPT
06Z/01
12Z/1 SEPT.
18Z/1
00Z/2
06Z/2
12Z/2
18Z/2
00Z/3
06Z/3
PRINTOUT LOST ON HERPA
12Z/3
18Z/3
00Z/4
06Z/4
12Z/4
18Z/4
00Z/6
06Z/5
12Z/5
18Z/5
00Z/6
06Z/6

Figure 1

Figure 2



TOTAL KINETIC ENERGY 12 HR CYCLE
TEP1) 6th LAYER
.80
.75
.70
0
6
12
27/12Z
28/00Z
28/12Z
29/00Z
29/12Z
30/00Z
30/12Z
31/00Z
31/12Z
01/00Z
01/12Z
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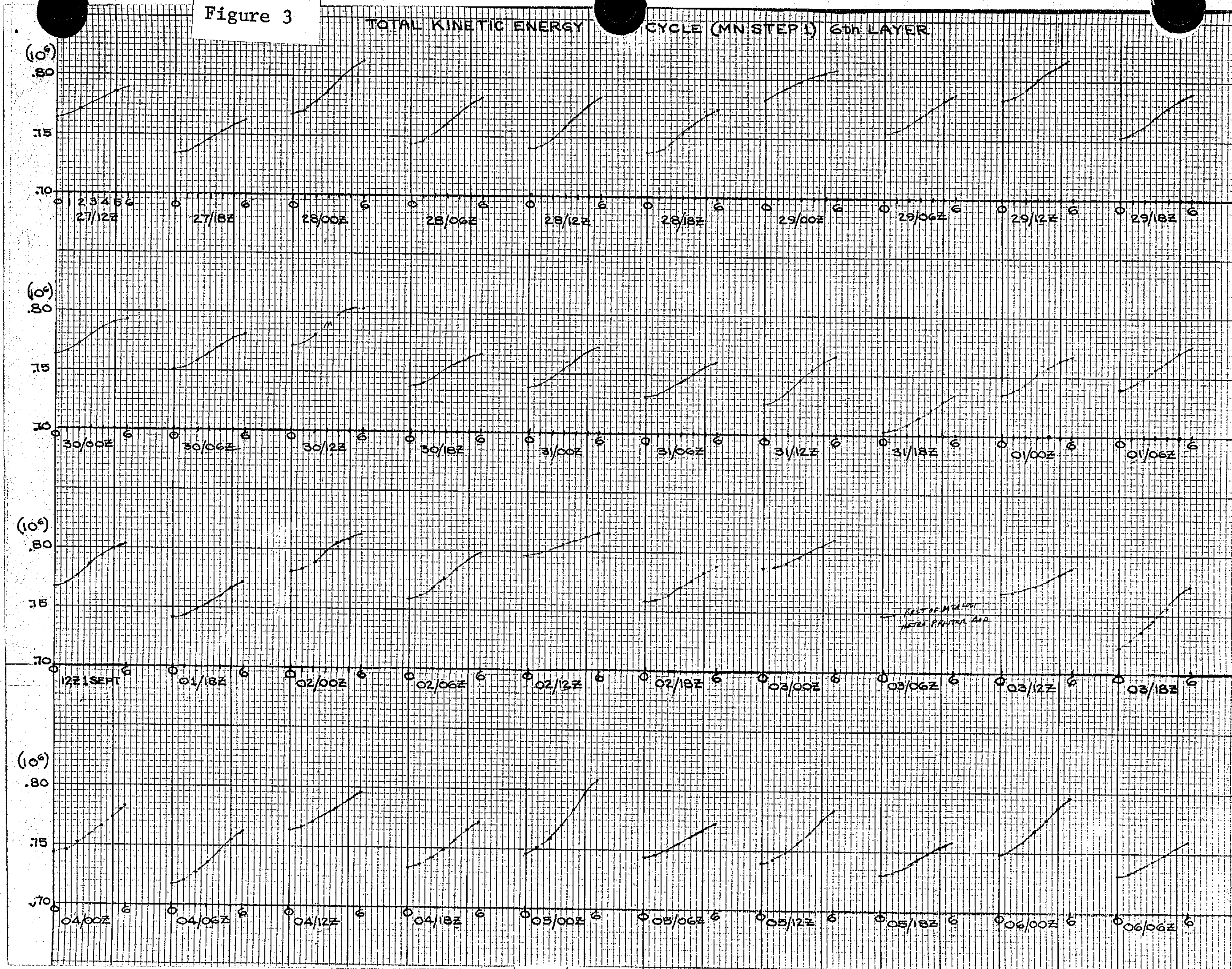
06/00
06/12

Figure 3



TOTAL KINETIC ENERGY CYCLE (MN STEP 1) 6th LAYER
(10⁶)
.80
.75
.70
0 1 2 3 4 5 6
27/12Z
27/18Z
28/00Z
28/06Z
28/12Z
28/18Z
29/00Z
29/06Z
29/12Z
29/18Z
30/00Z
30/06Z
30/12Z
30/18Z
31/00Z
31/06Z
31/12Z
31/18Z
01/00Z
01/06Z
12Z 1 SEPT
01/18Z
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03/06Z
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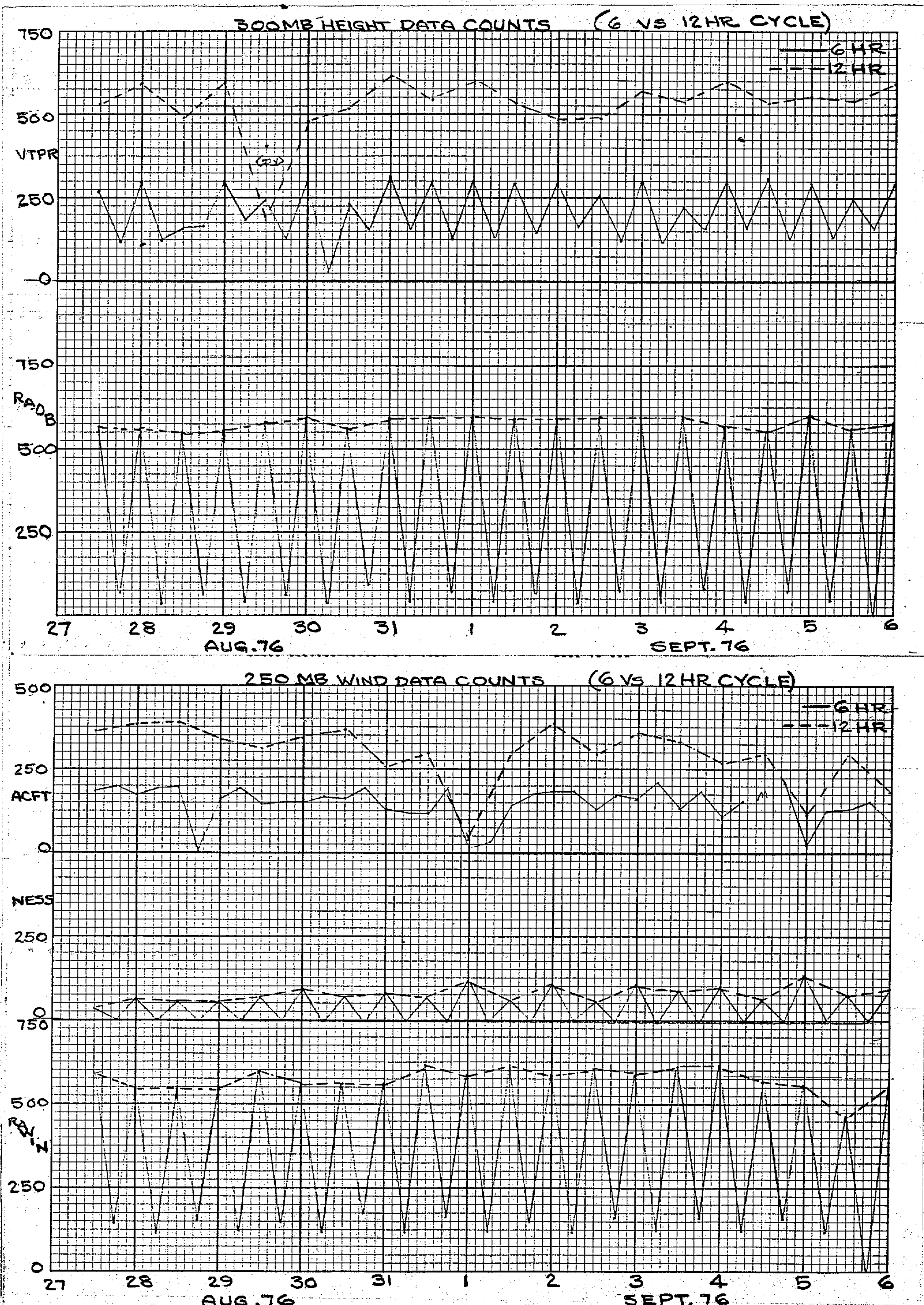
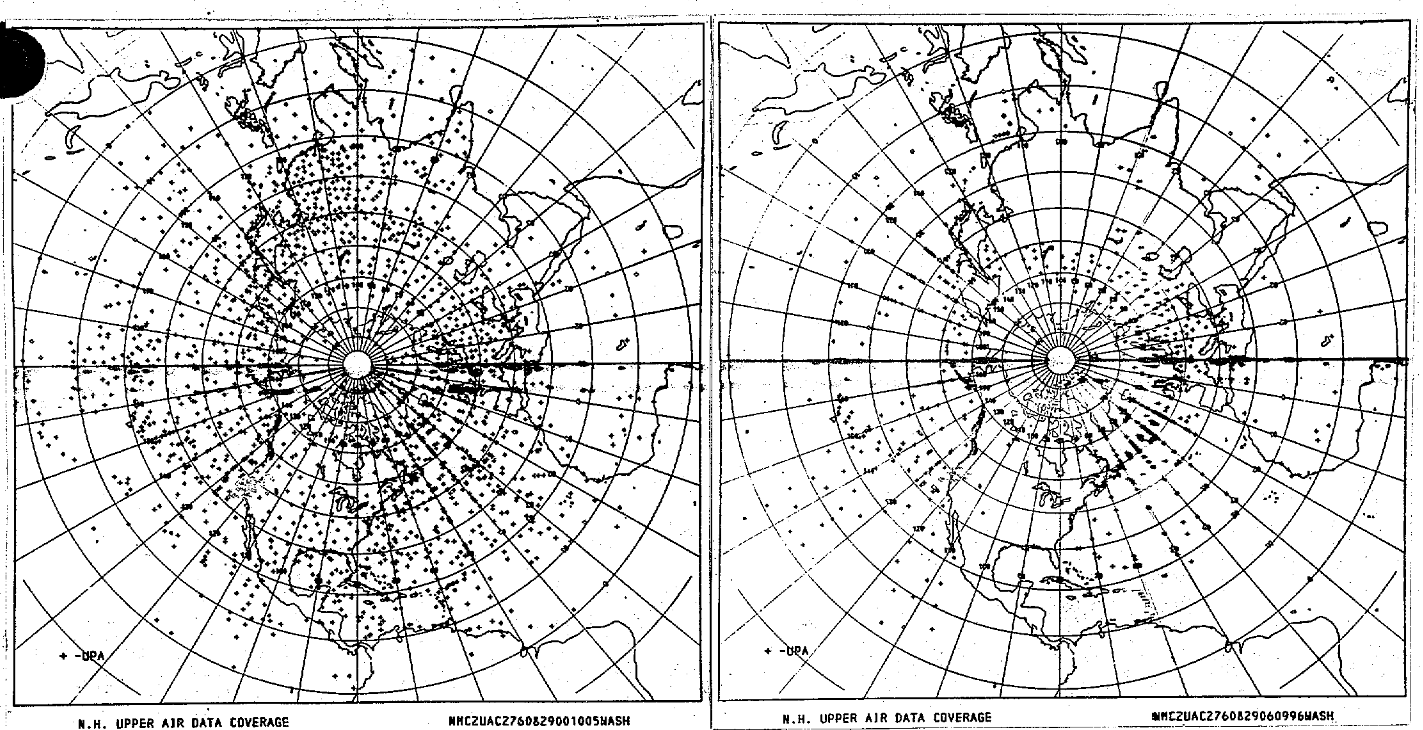
06/00Z
06/06Z



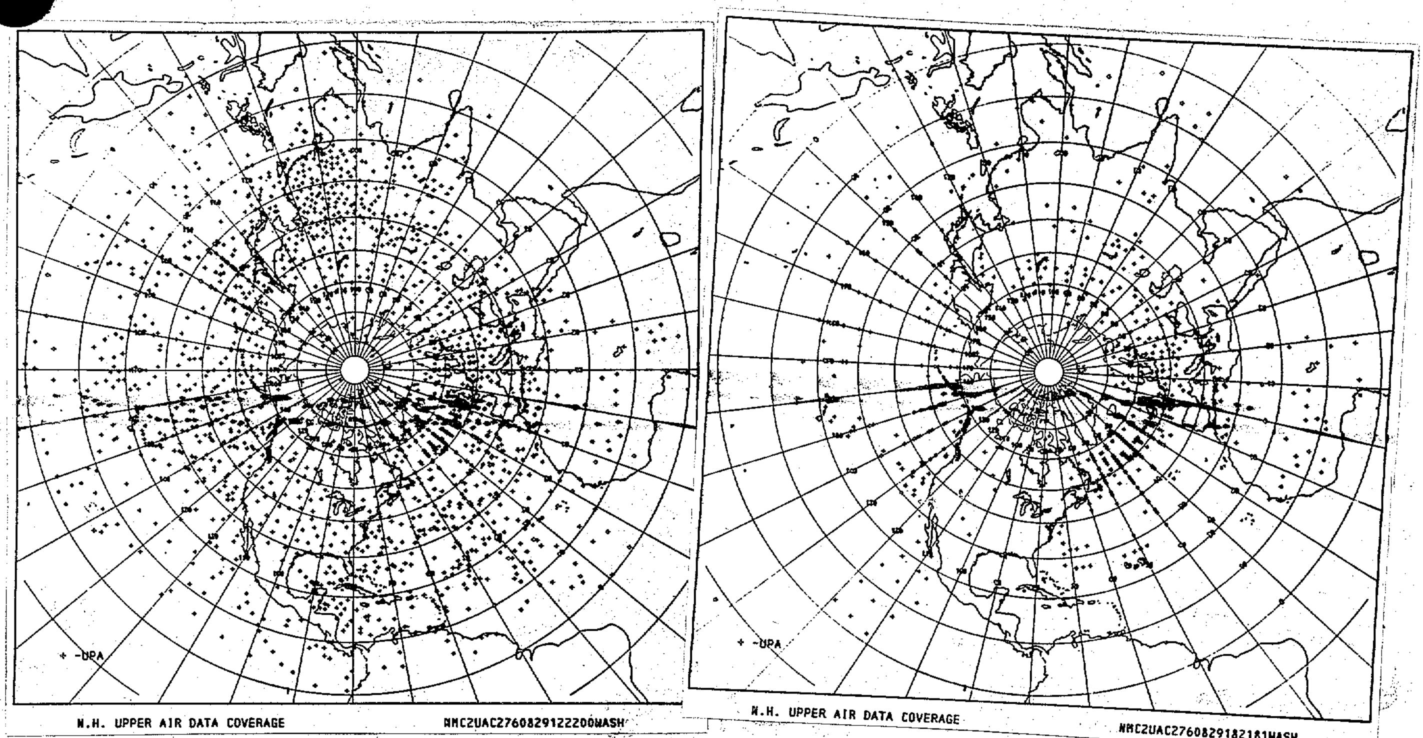
300MB HEIGHT DATA COUNTS (6 VS 12HR CYCLE)
6 HR
12 HR
750
500
VTPR
250
0
750
RAOB
500
250
27
28
29
30
31
1
2
3
4
5
6
AUG. 76
SEPT. 76
250 MB WIND DATA COUNTS (6 VS 12 HR CYCLE)
6 HR
12 HR
500
250
ACFT
0
NESS
250
0
750
500
RAWIN
250
0
27
28
29
30
31
1
2
3
4
5
6
AUG. 76
SEPT. 76

Figure 4

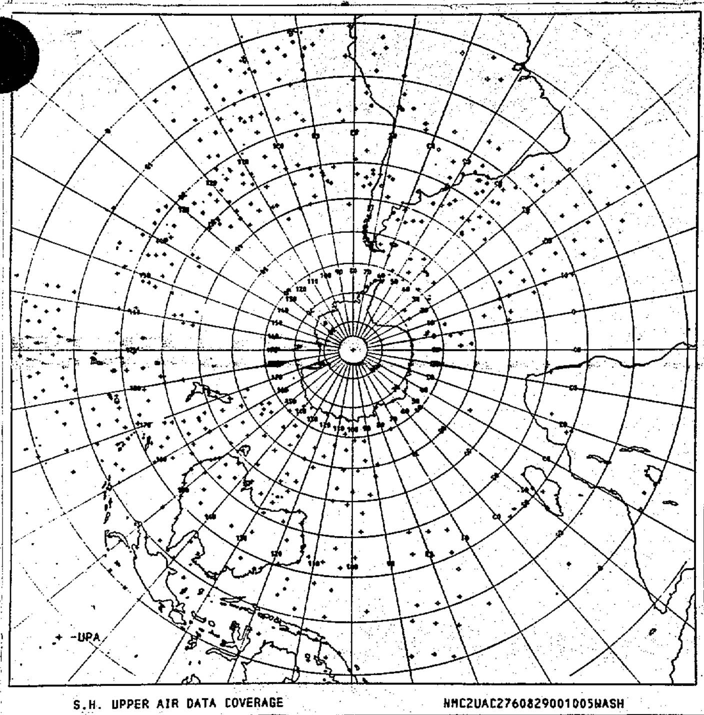


a. b.

Figure 5 Six hourly N.H. upper-air data coverage for 24-hrs 29 Aug. 1976



c. d.



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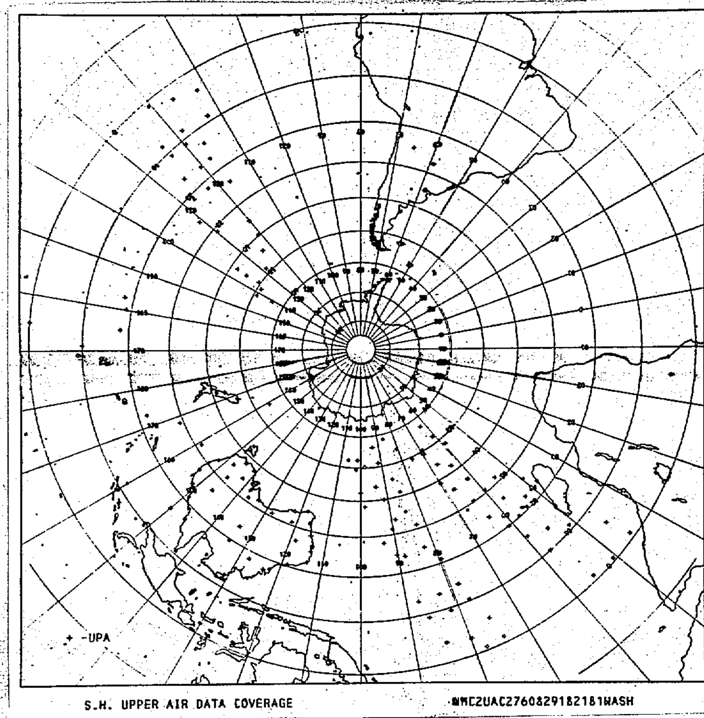
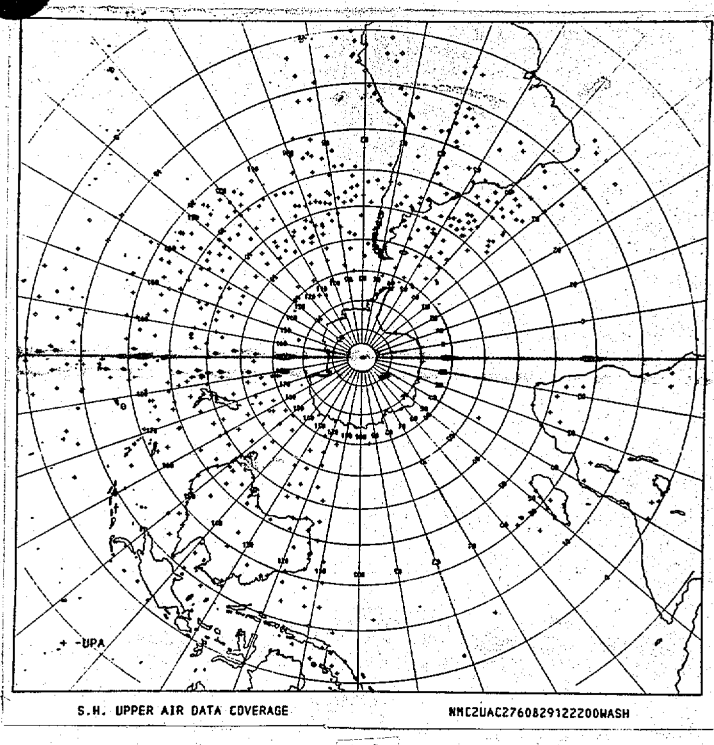
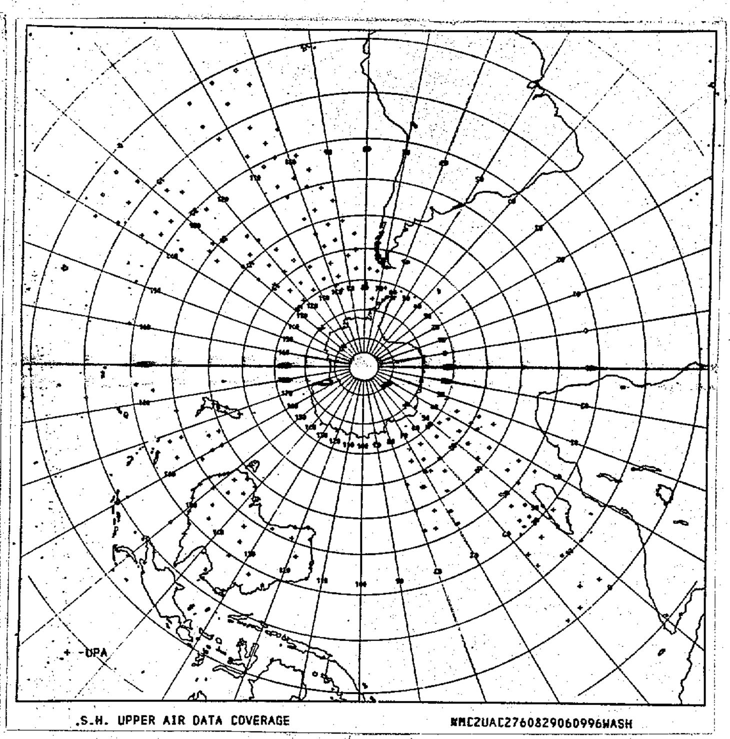


b.

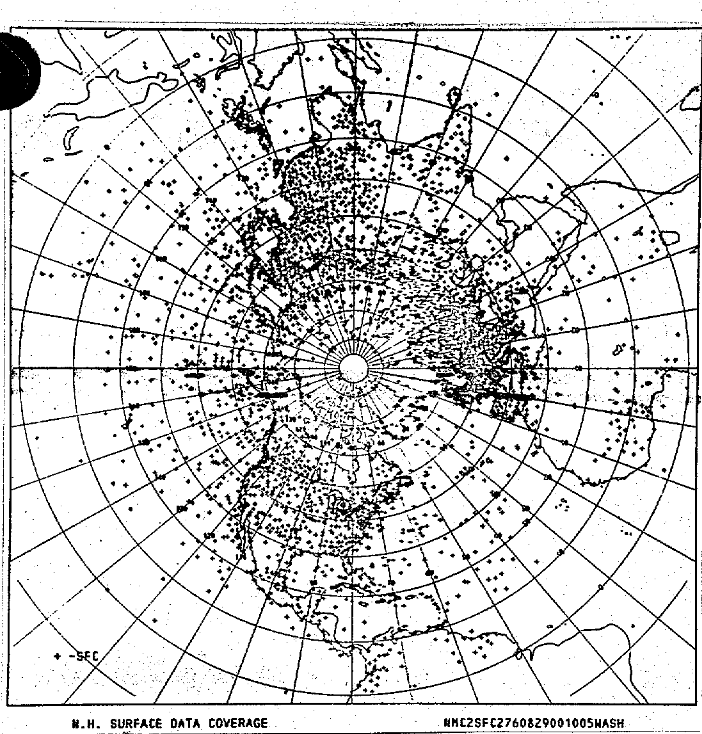
Figure 6 Six hourly S.H. upper-air data coverage for 24-hrs 29 Aug. 1976



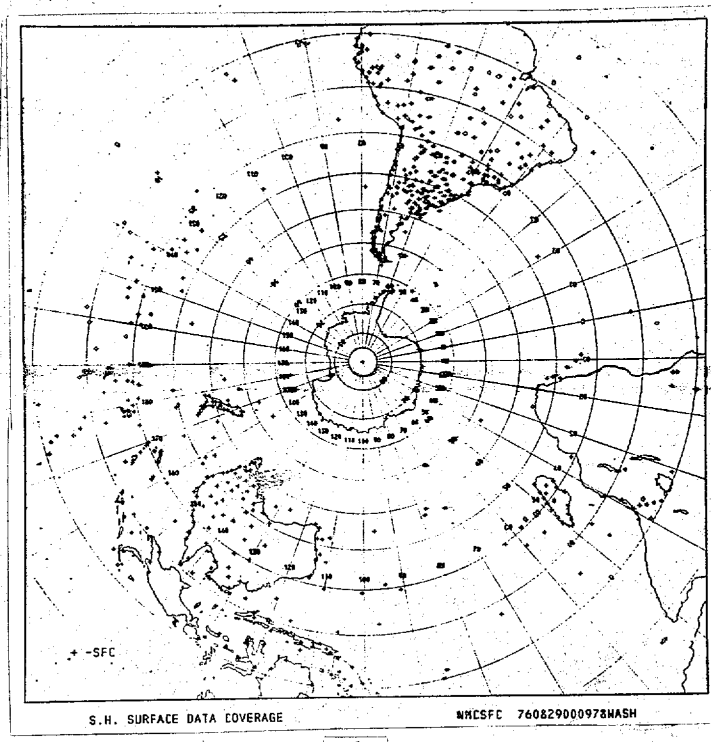
c.



d.

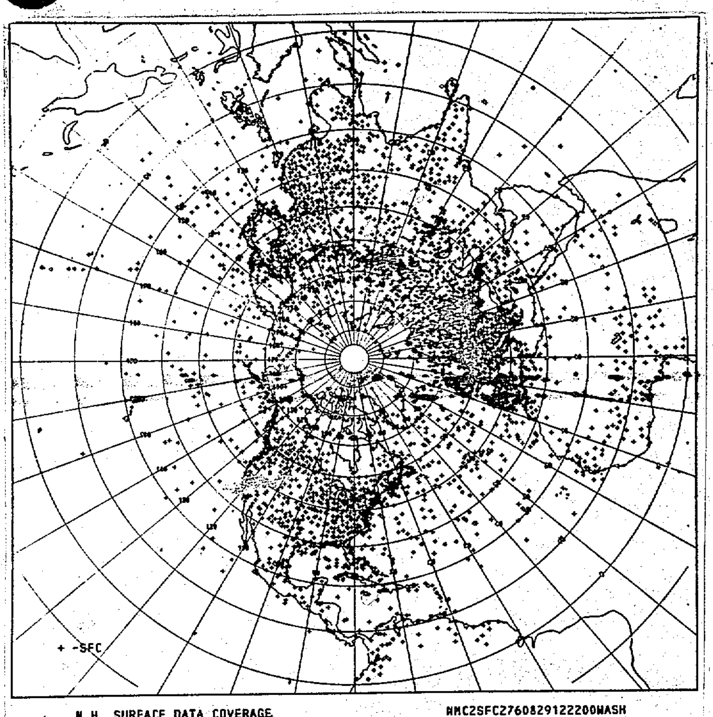


a.



b.

Figure 7	Six hourly N.H. surface data coverage for 24-hrs 29 Aug. 1976



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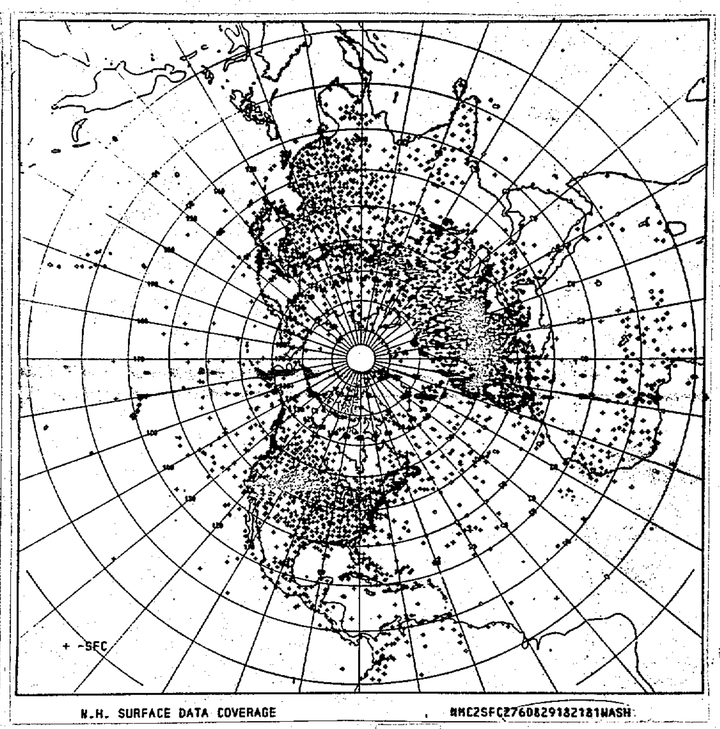


d.

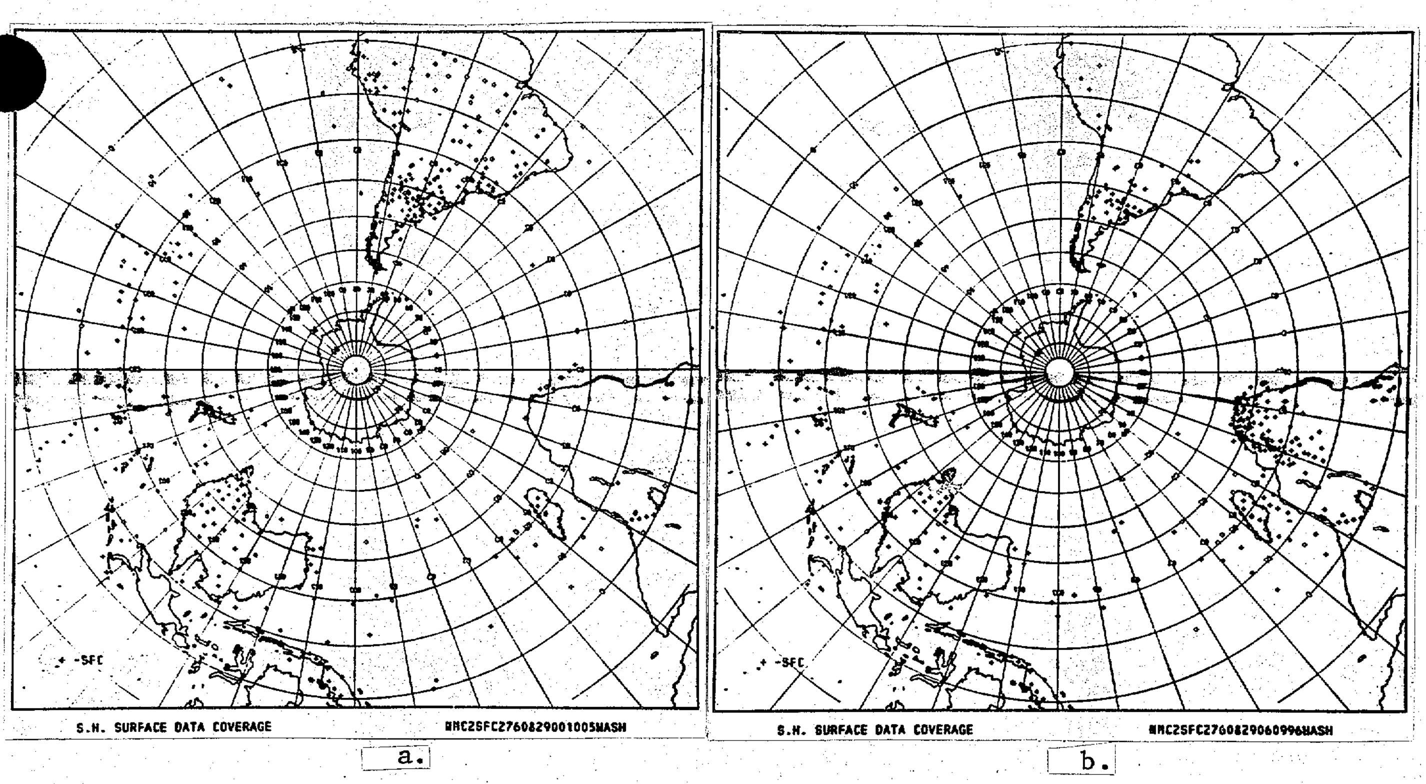
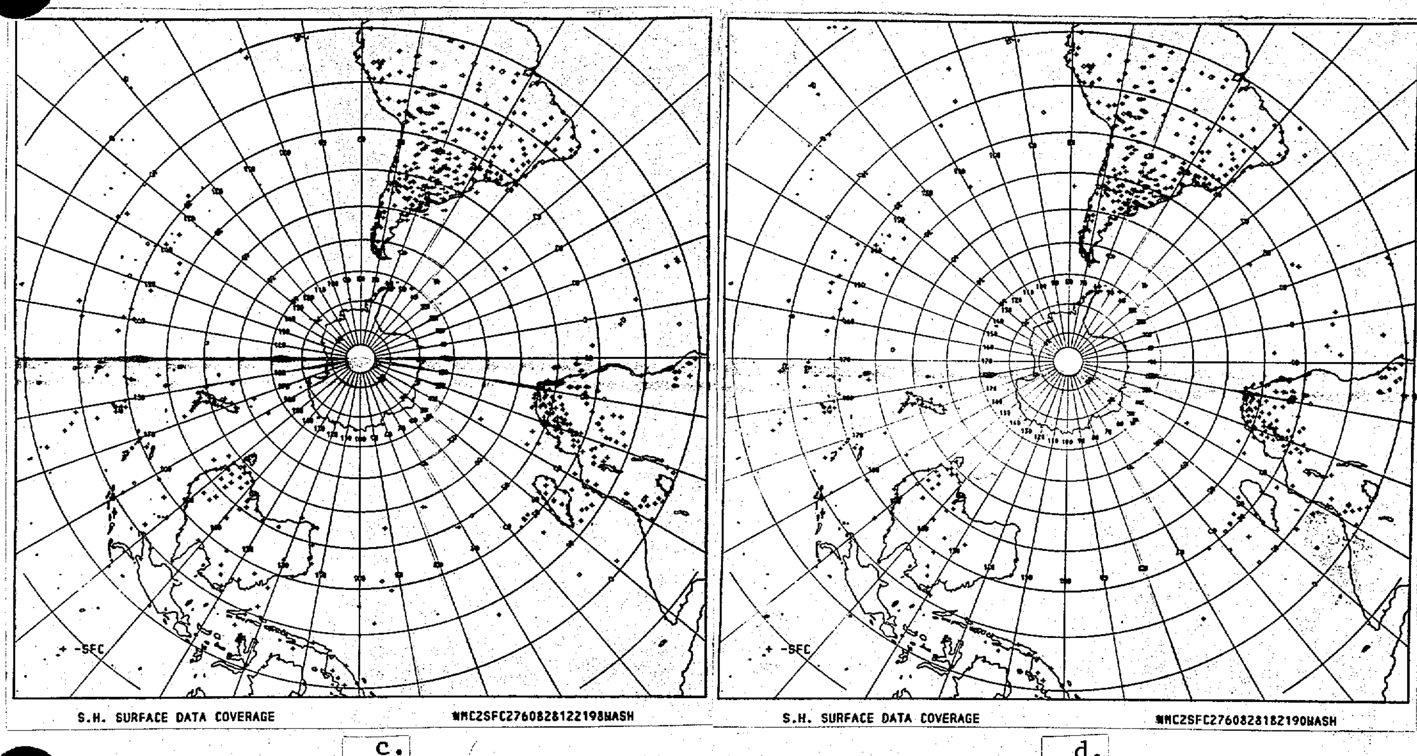
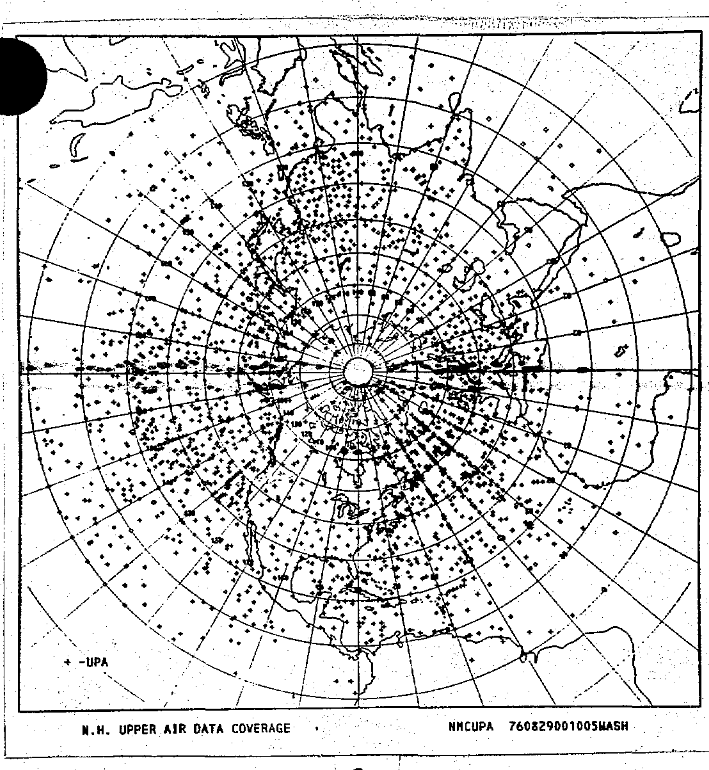
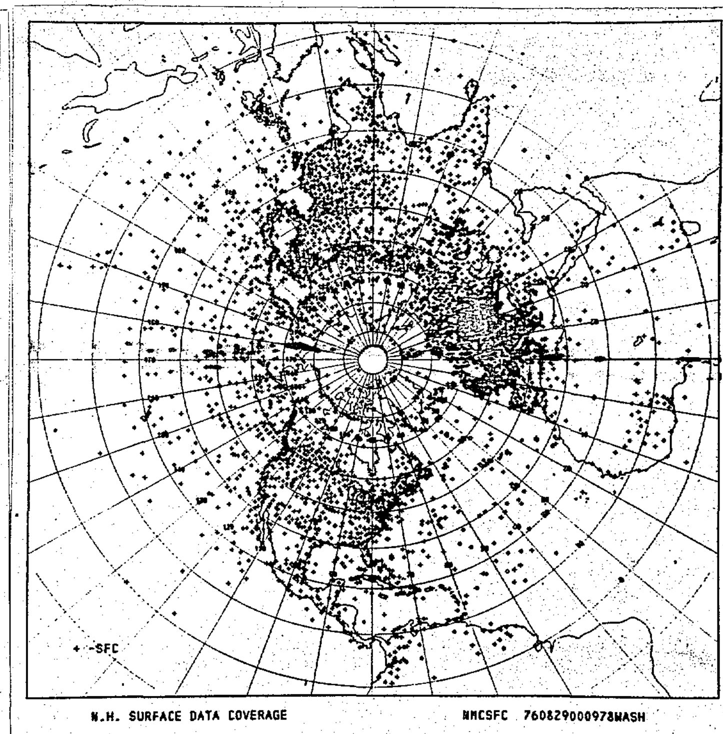


Figure 8 Six hourly S.H. surface data coverage for 24-hrs 29 Aug. 1976





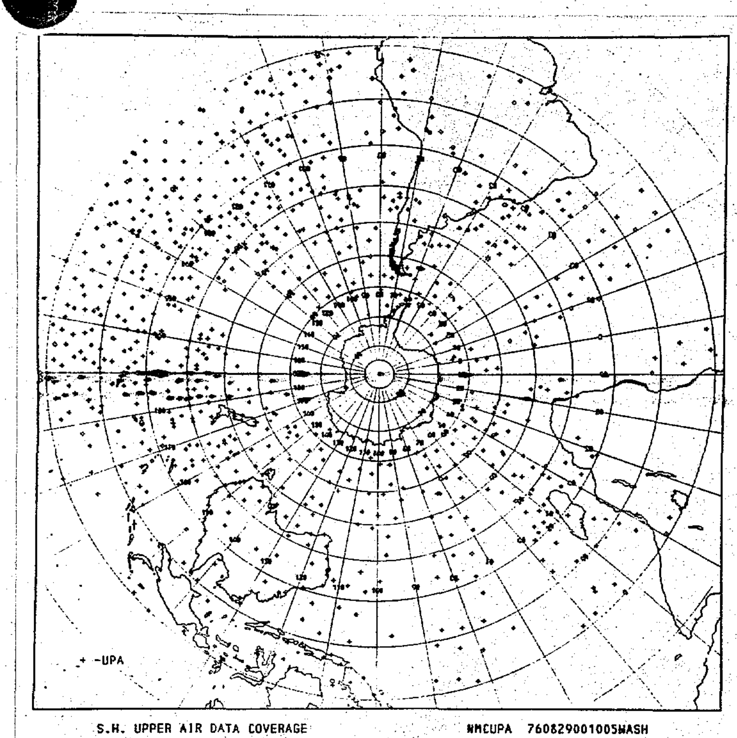
a.



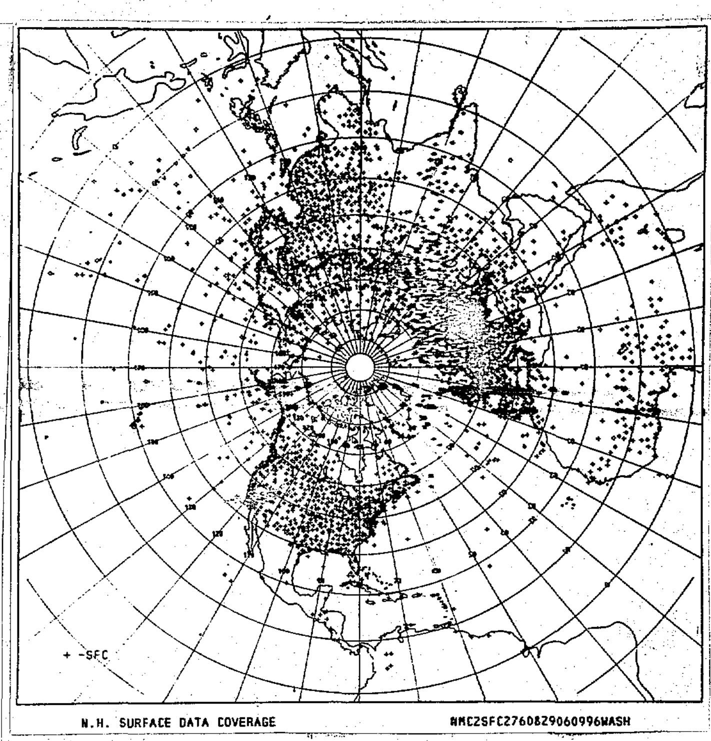
b.

12-HR CYCLE UPPER AIR DATA

12-HR CYCLE SURFACE DATA



c.



d.

Figure 9

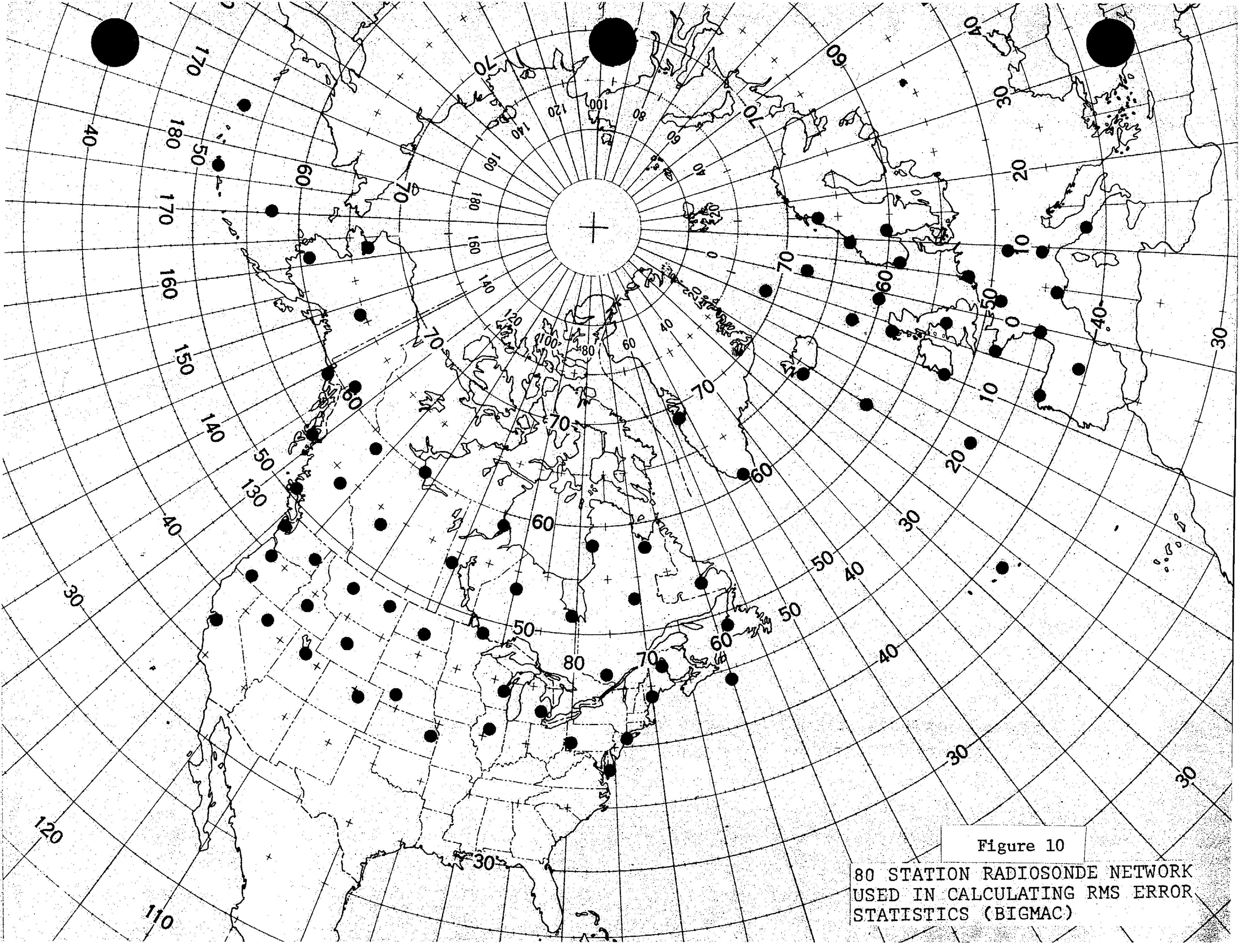


Figure 10

80 STATION RADIOSONDE NETWORK USED IN CALCULATING RMS ERROR STATISTICS (BIGMAC)

Figure 11a

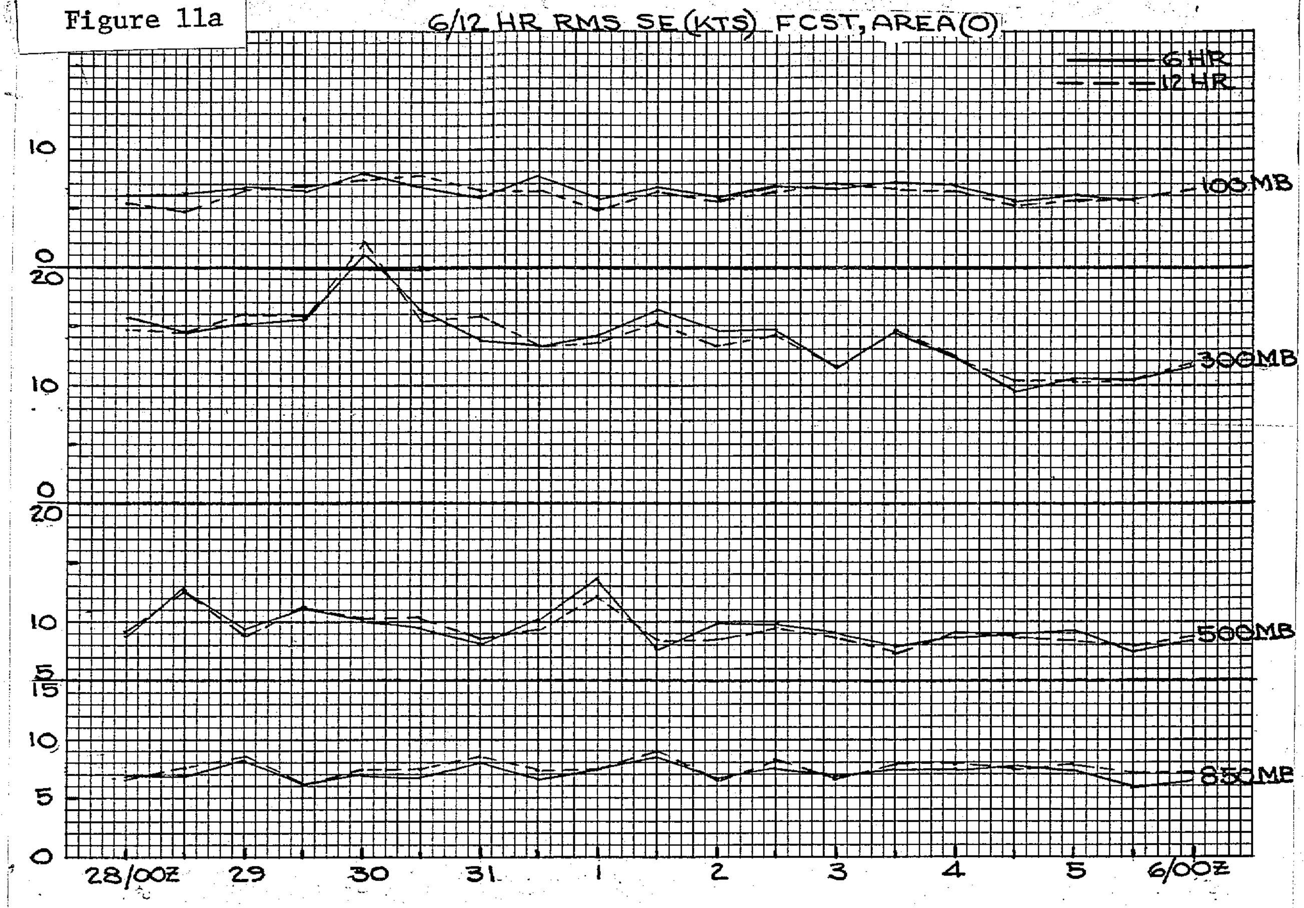


Figure 11b

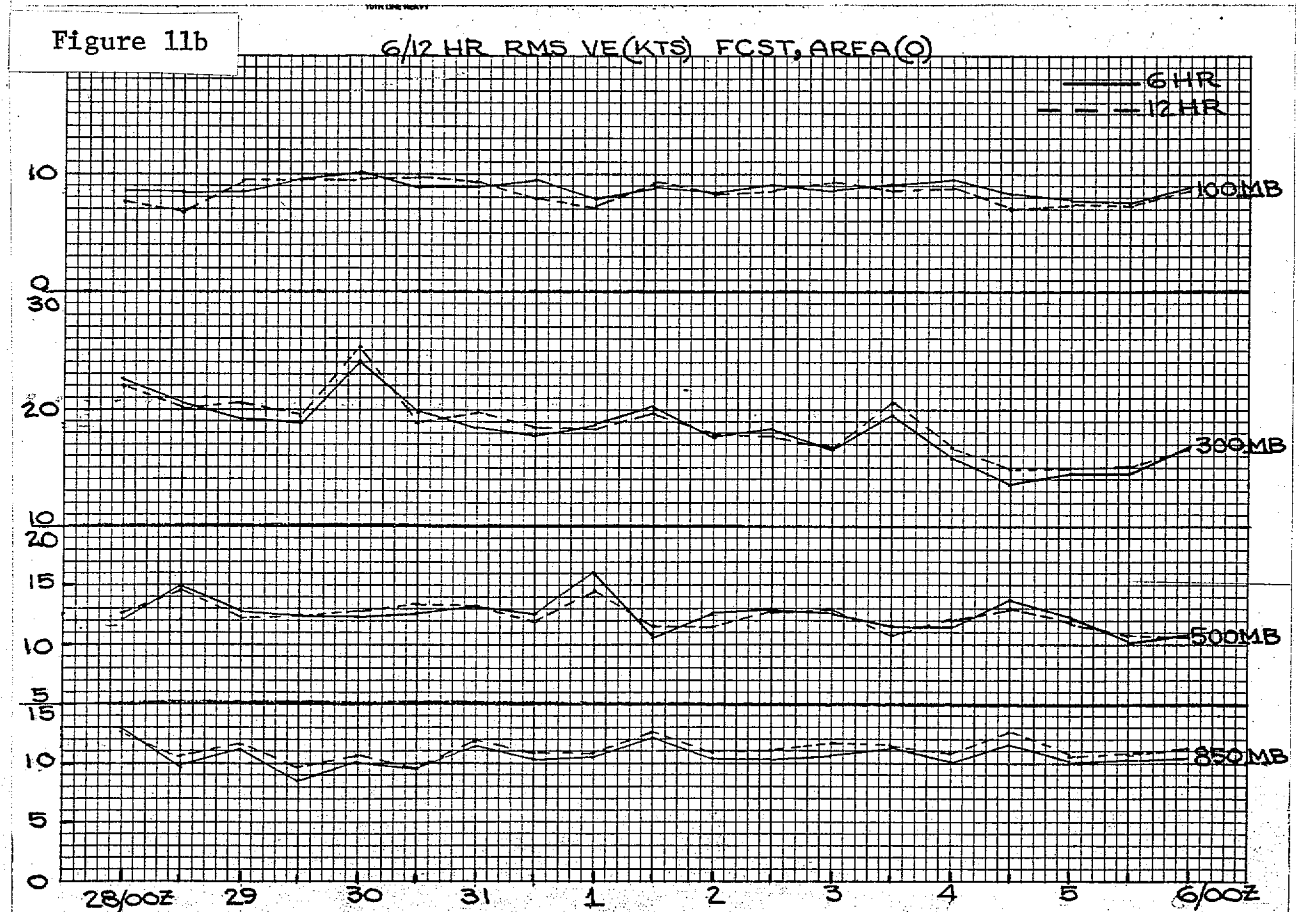


Figure 12a

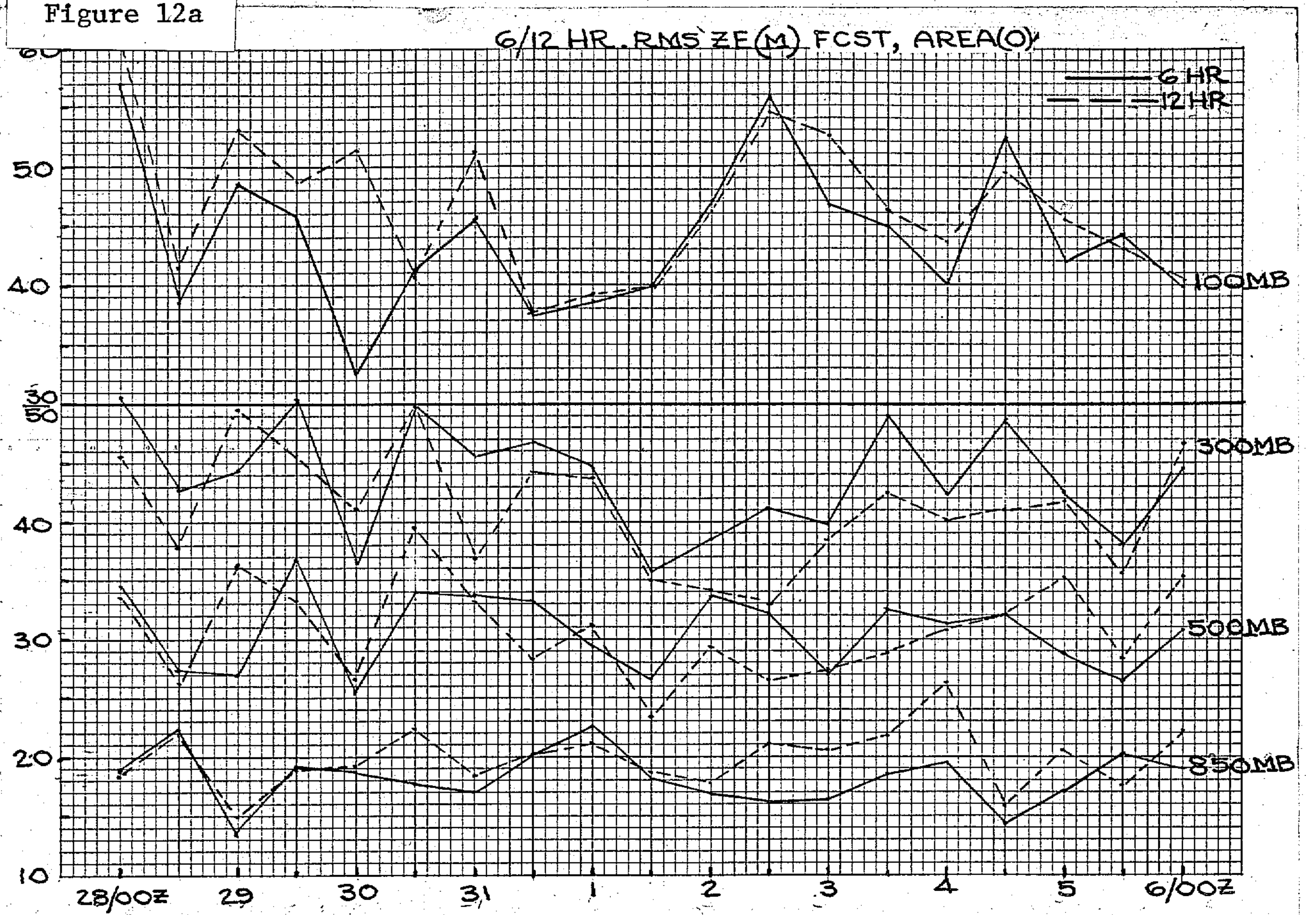
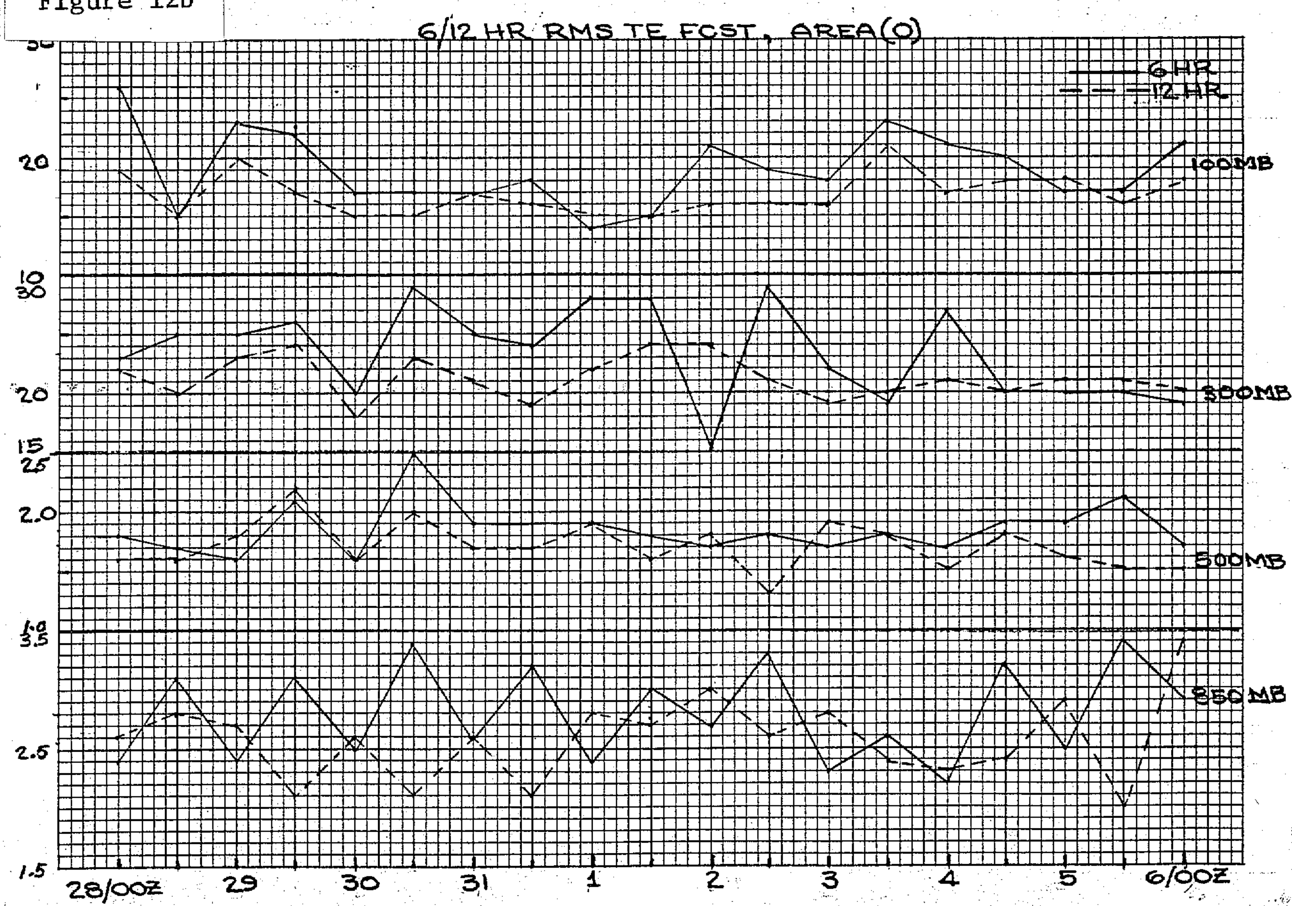


Figure 12b



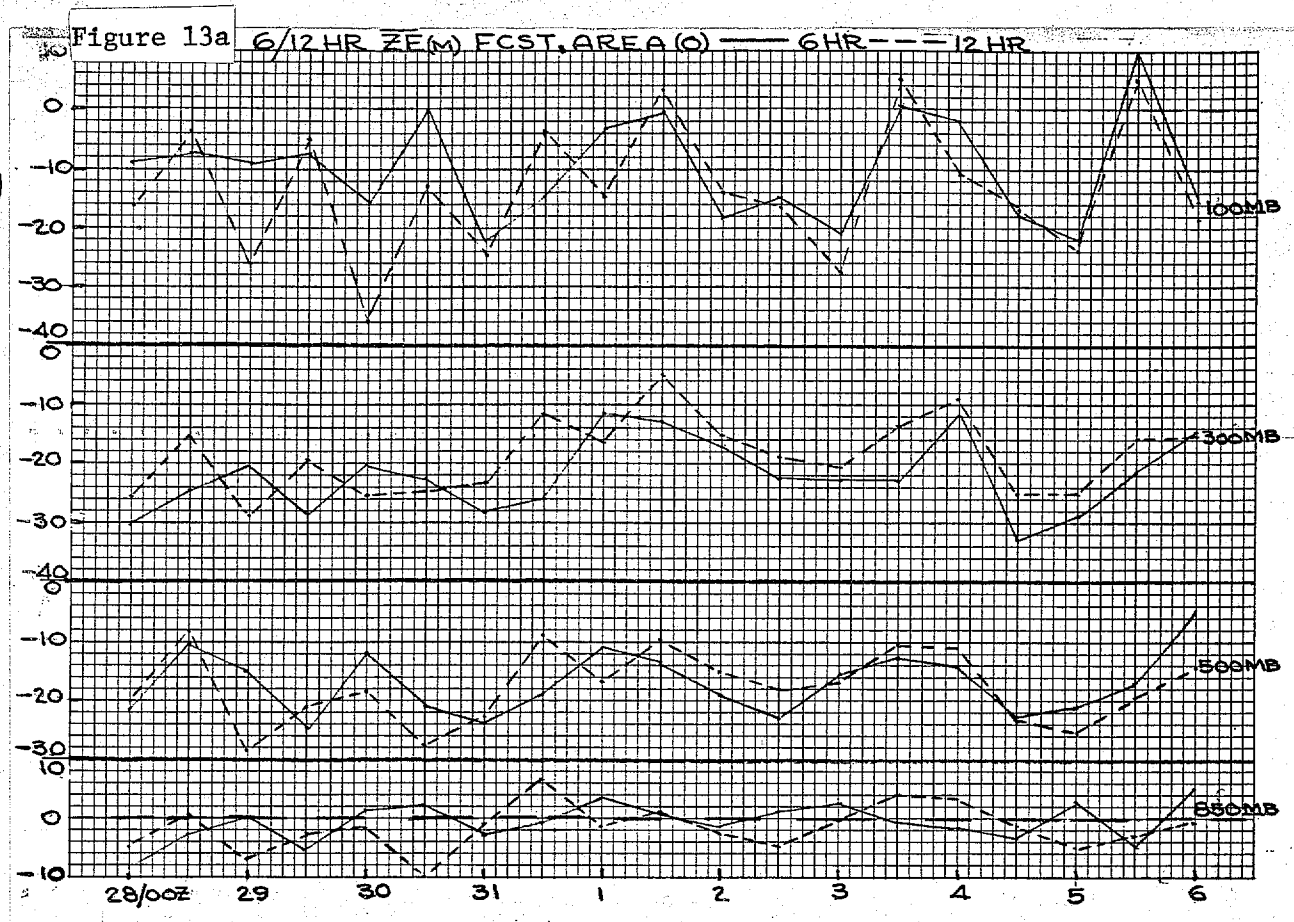


Figure 13a
6/12 HR ZE(M) FCST, AREA (O) —— 6HR - - - 12 HR
100MB
300MB
500MB
850MB
28/00Z
29
30
31
1
2
3
4
5
6

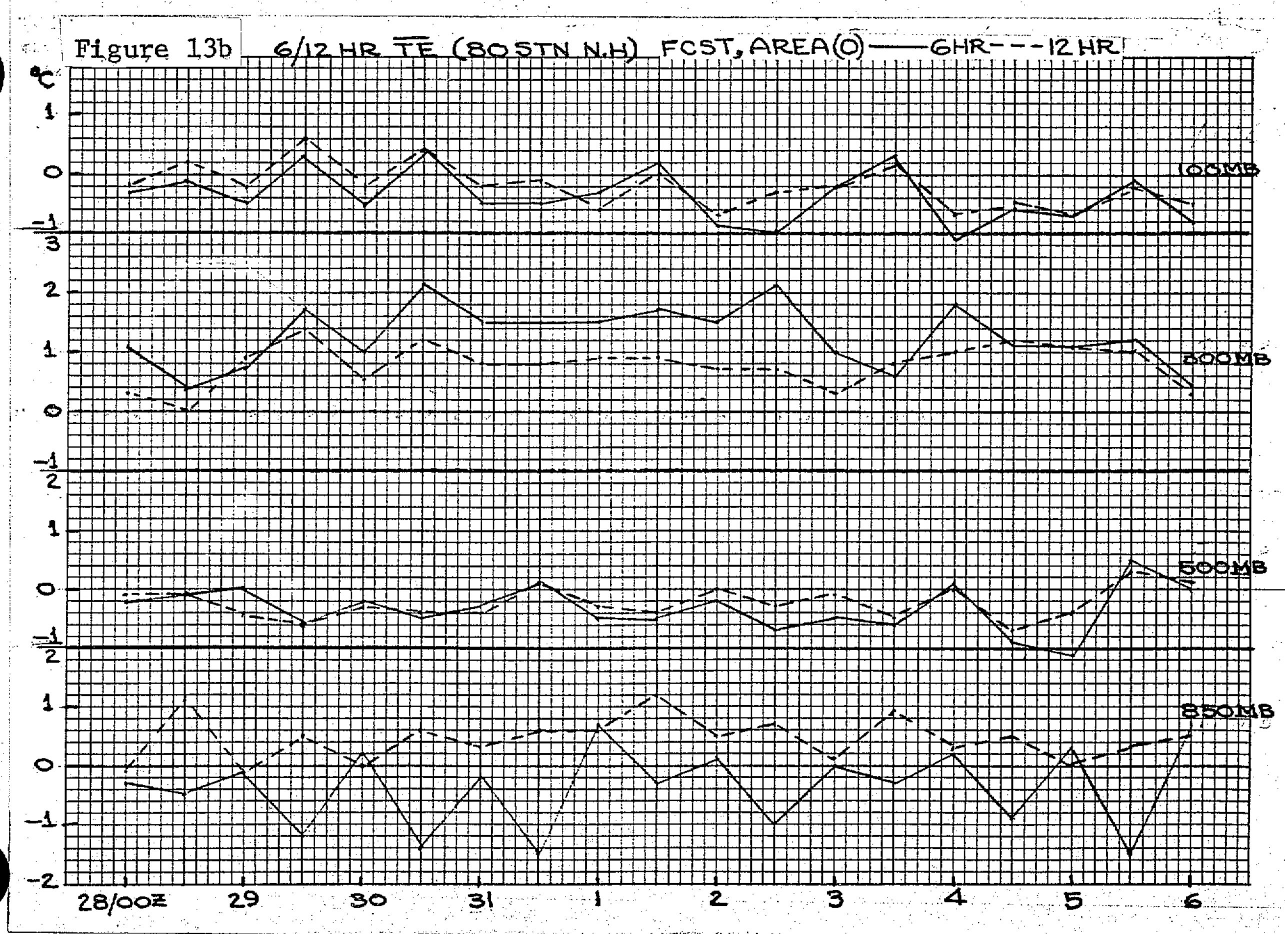


Figure 13b
6/12 HR TE (80 STN N.H) FCST, AREA (O) —— 6HR - - - 12 HR
°C
100MB
300MB
500MB
850MB
28/00Z
29
30
31
1
2
3
4
5
6

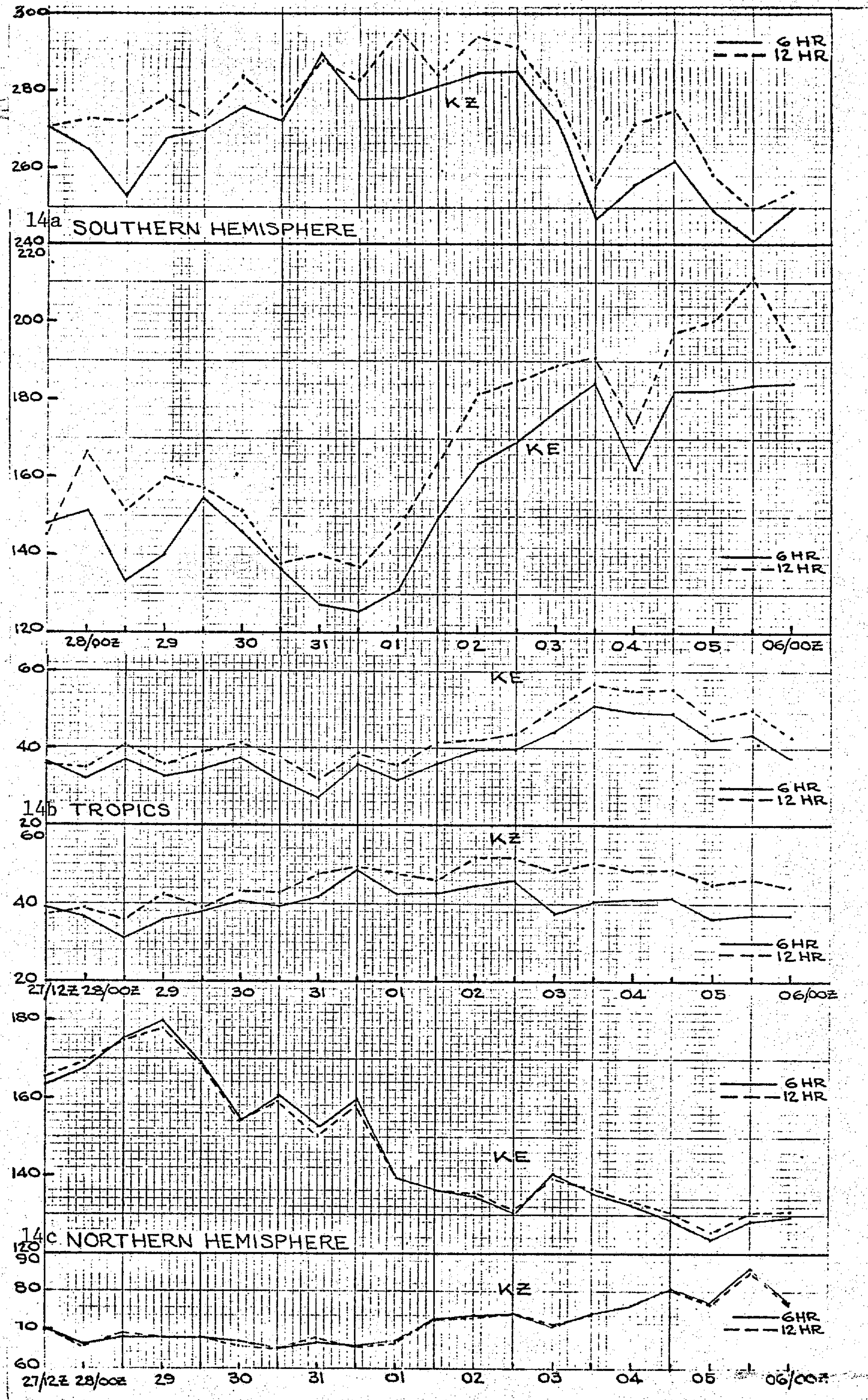


Figure 14. 300 mb zonal (KZ) and eddy kinetic (KE) energy levels from the analyses (units joules/kg m). The 6-hour is shown as solid and the 12-hour as dashed.

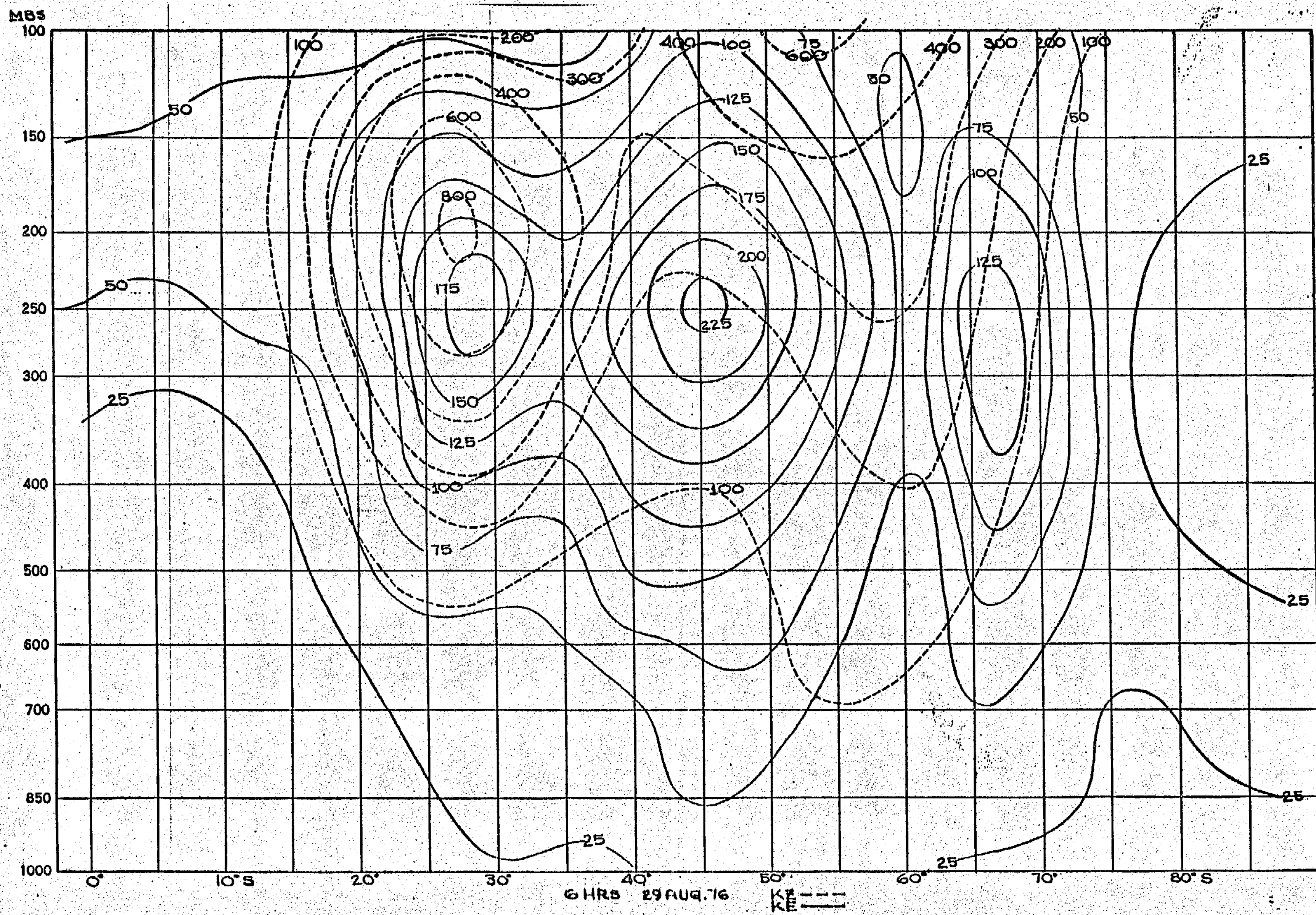


Figure 15. Zonal Average of KZ and KE (6-hour cycle) from 00Z, August 29, 1976 Analyses.

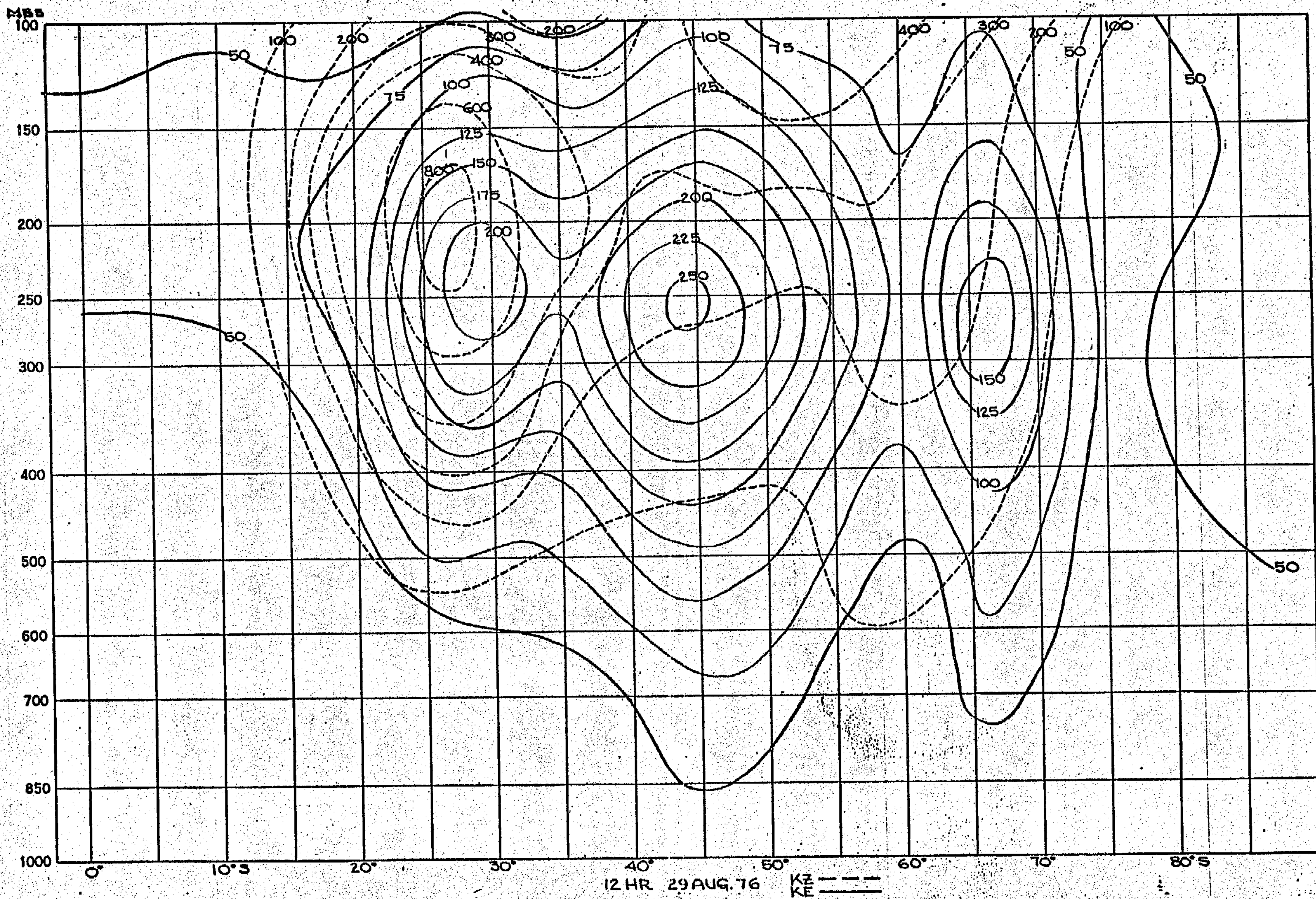


Figure 16. Zonal Average of KZ and KE (12-hour cycle) from 00Z, August 29, 1976 Analyses.

Figure 17a

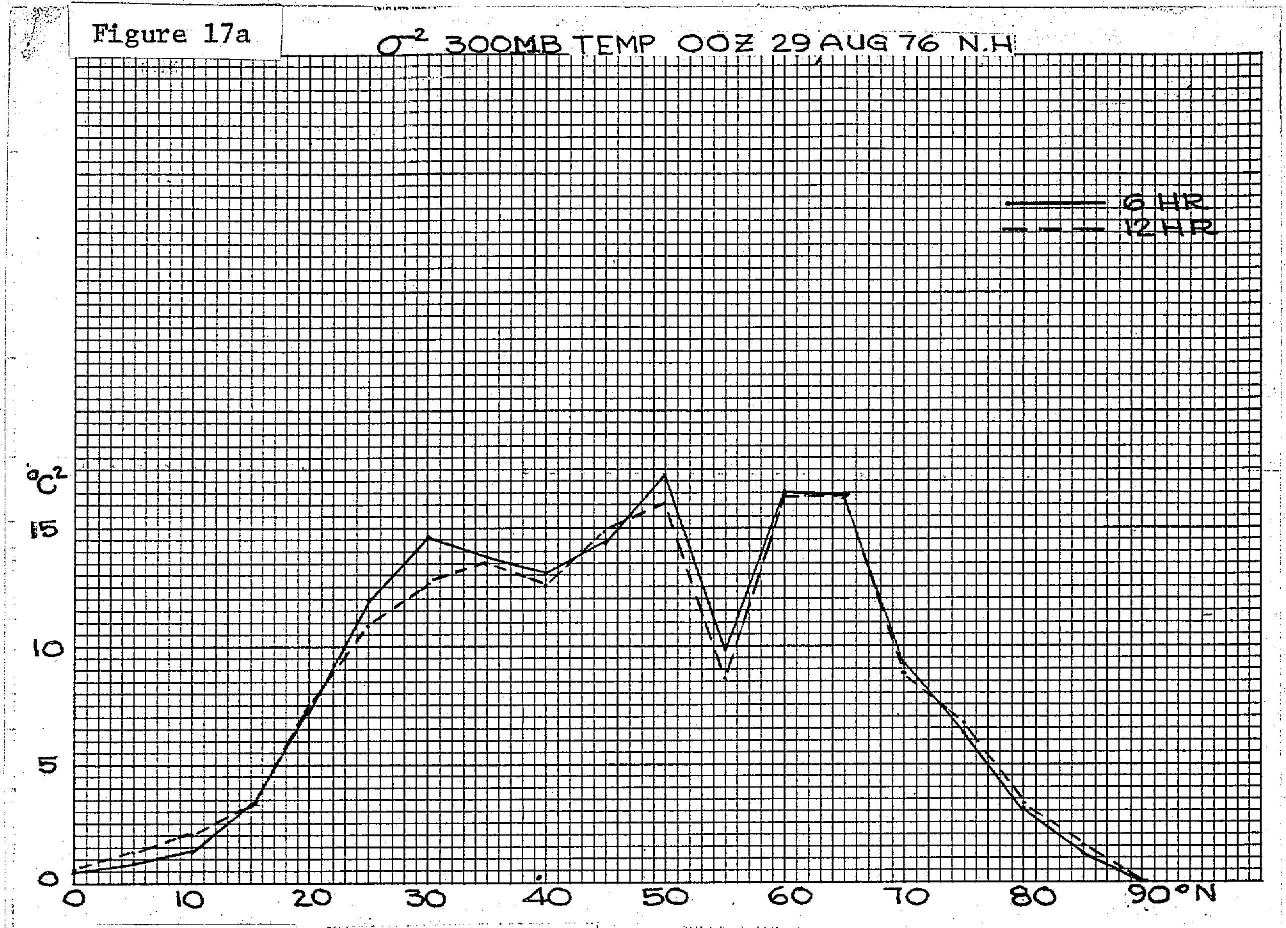


Figure 17b

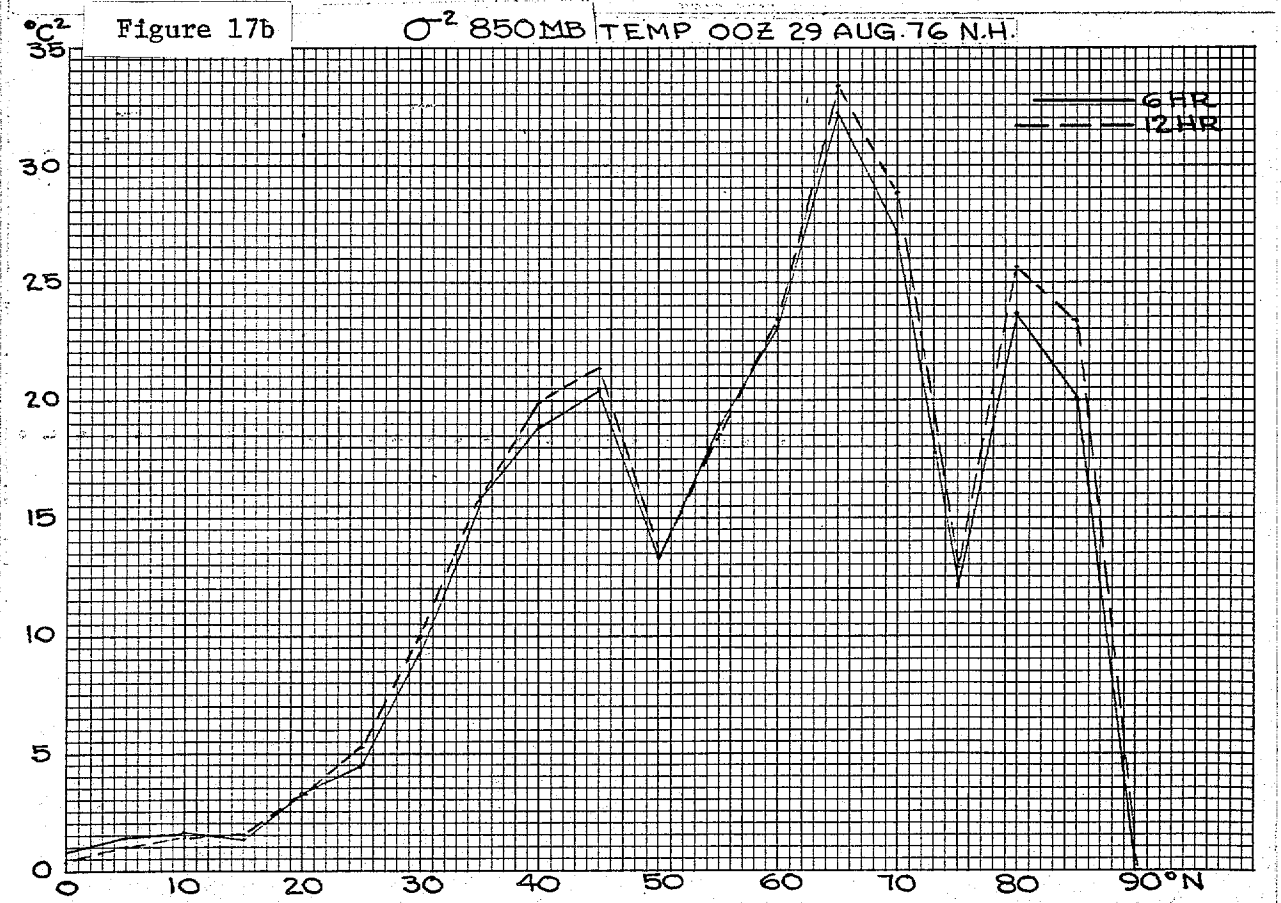


Figure 18a

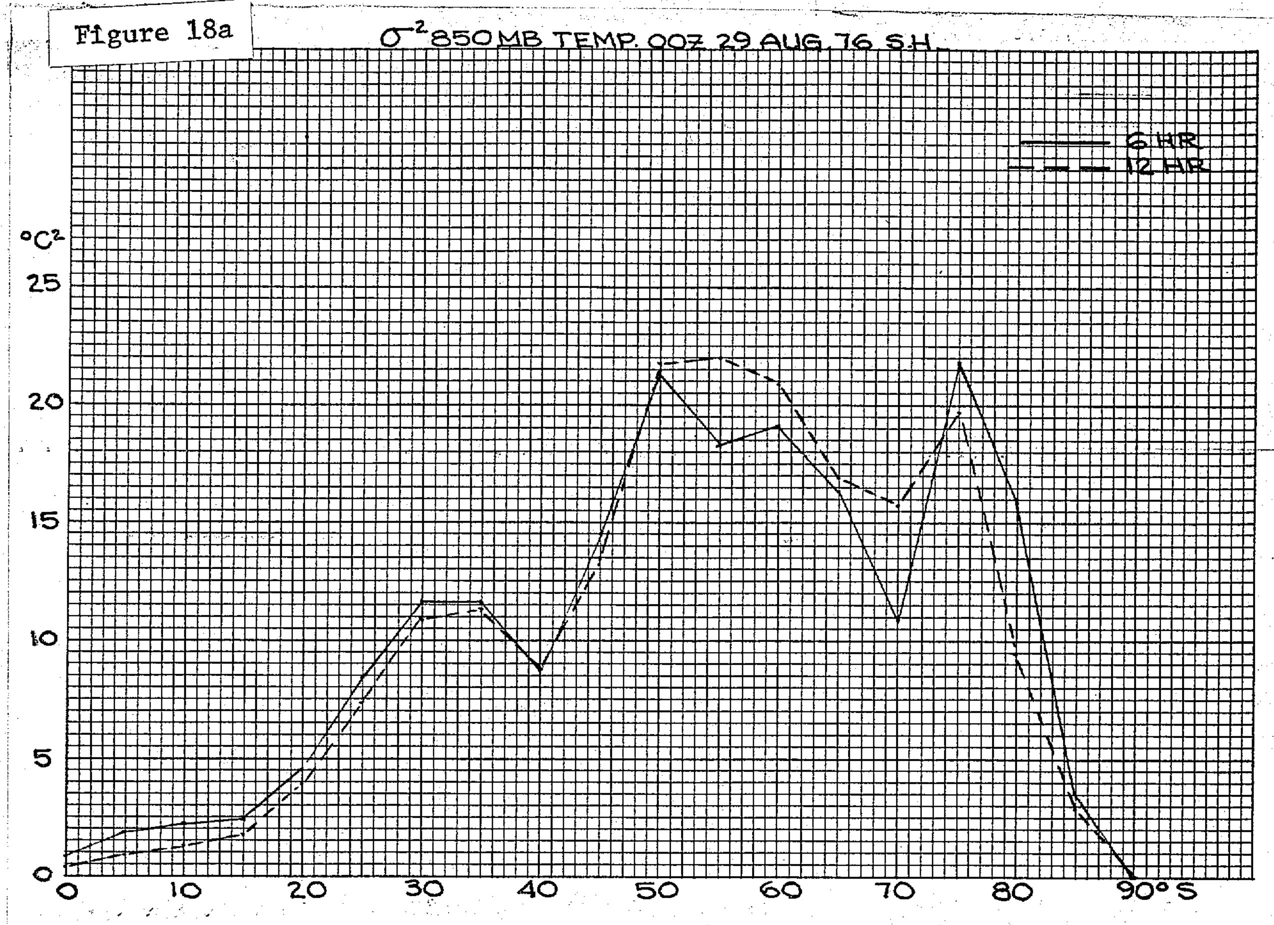


Figure 18b

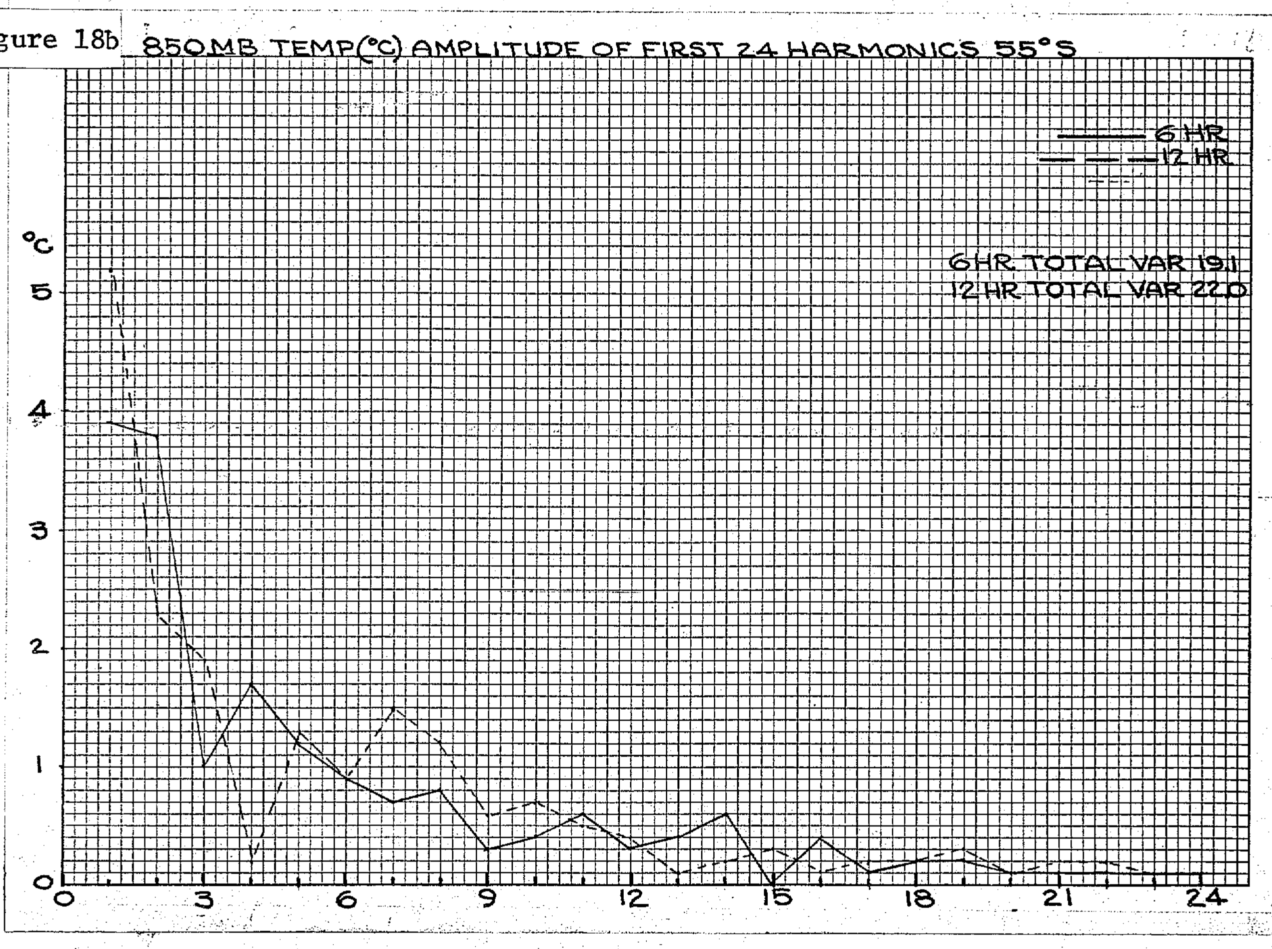


Figure 19a

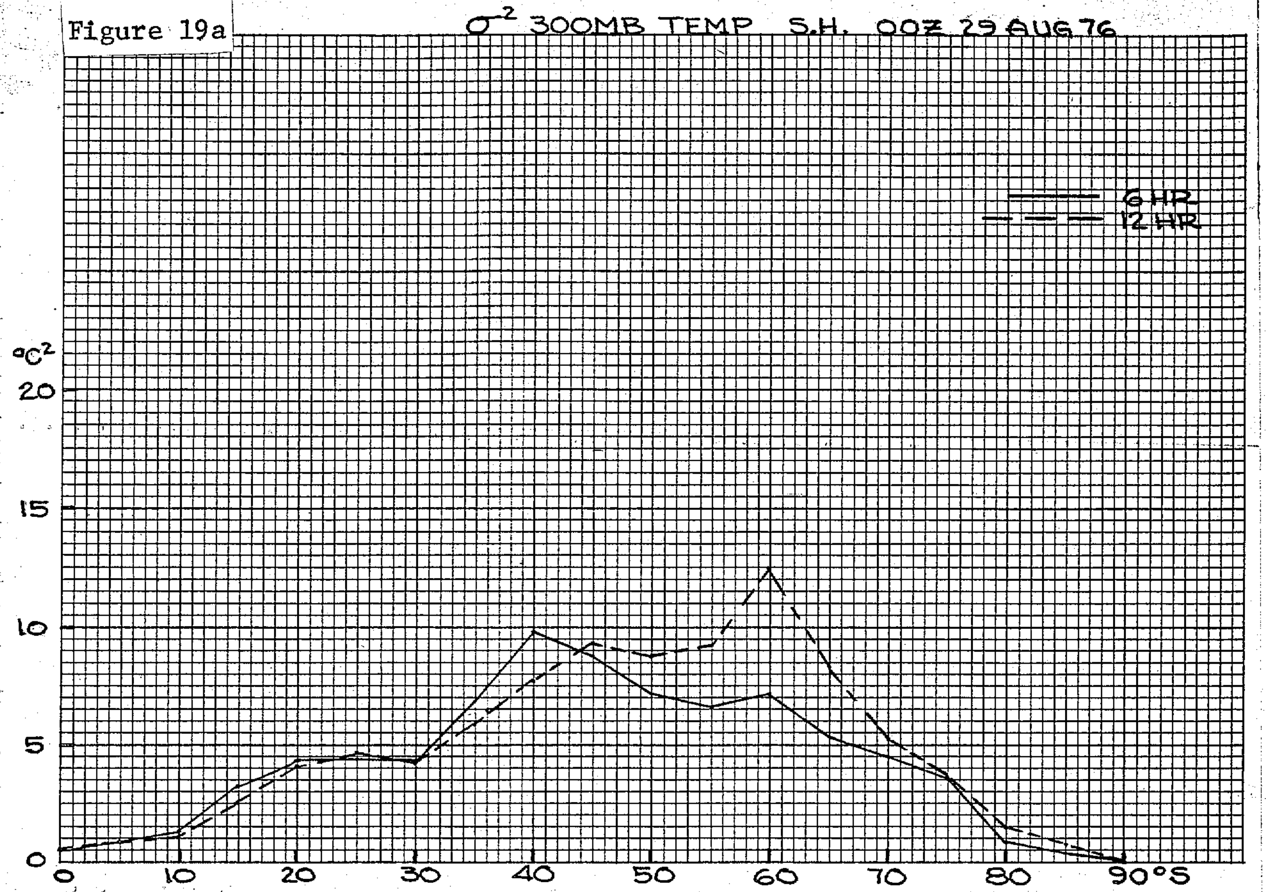
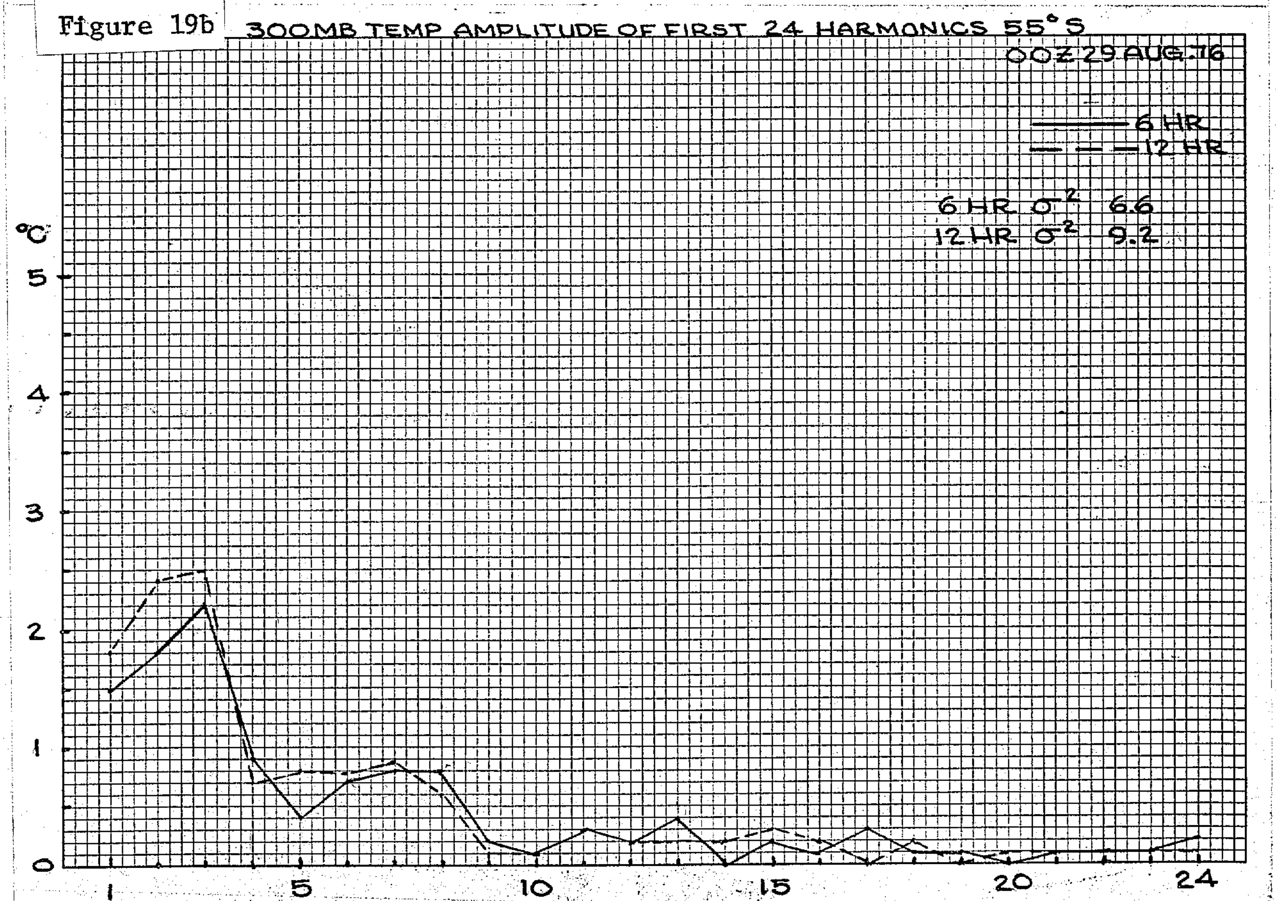
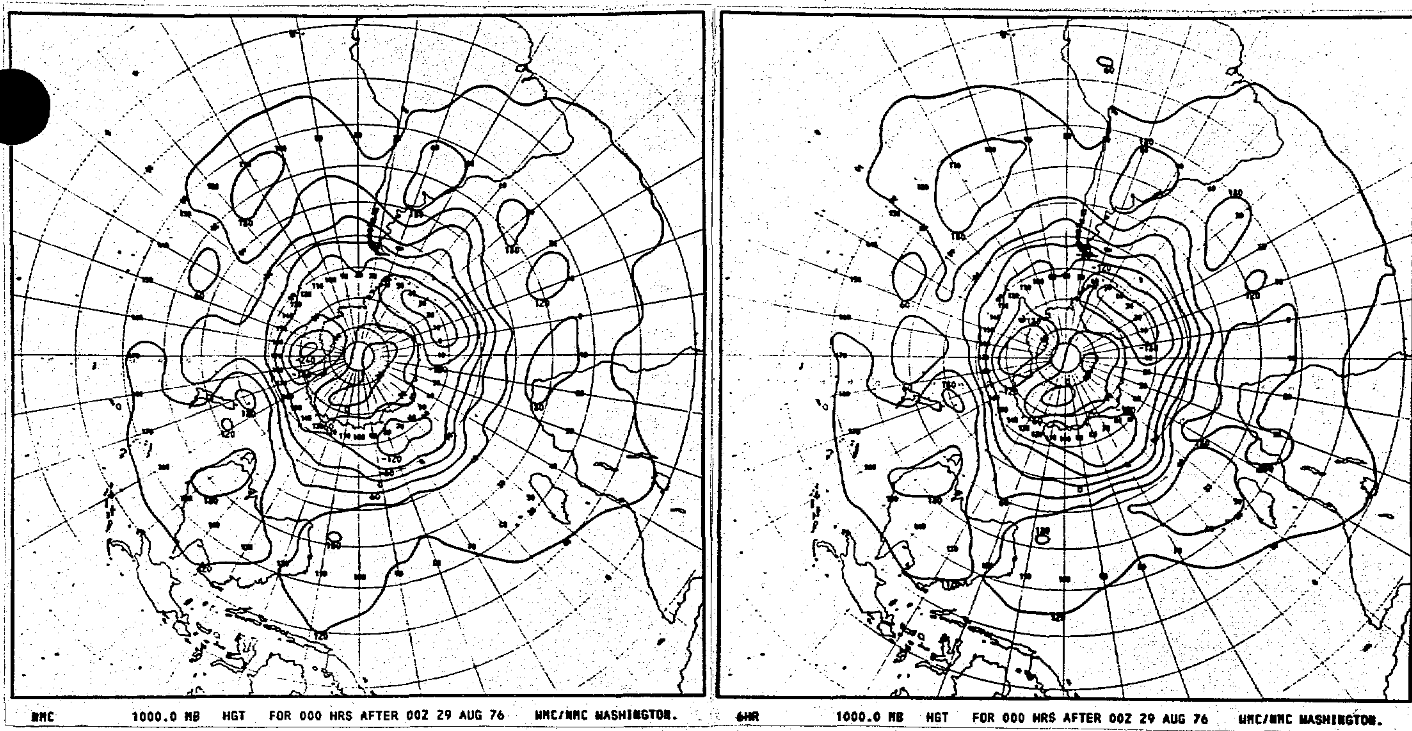


Figure 19b

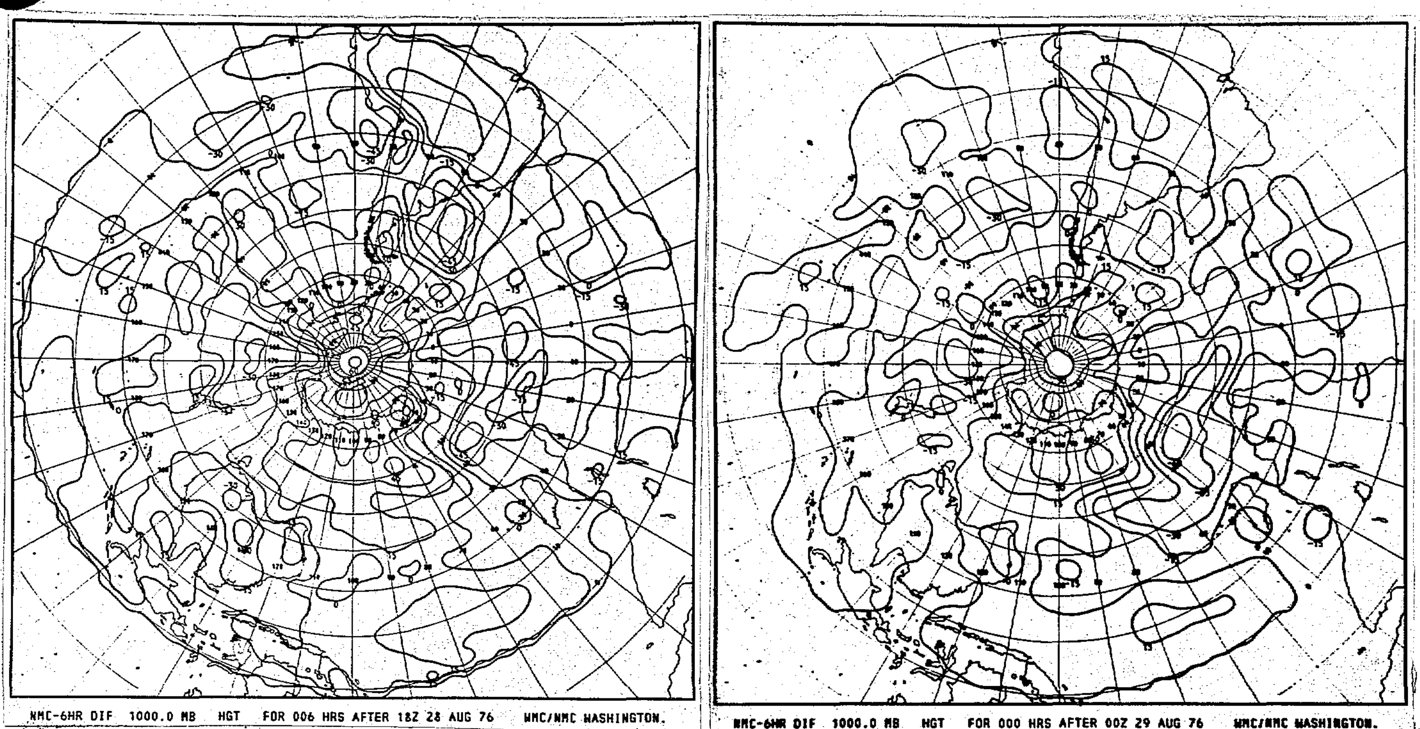




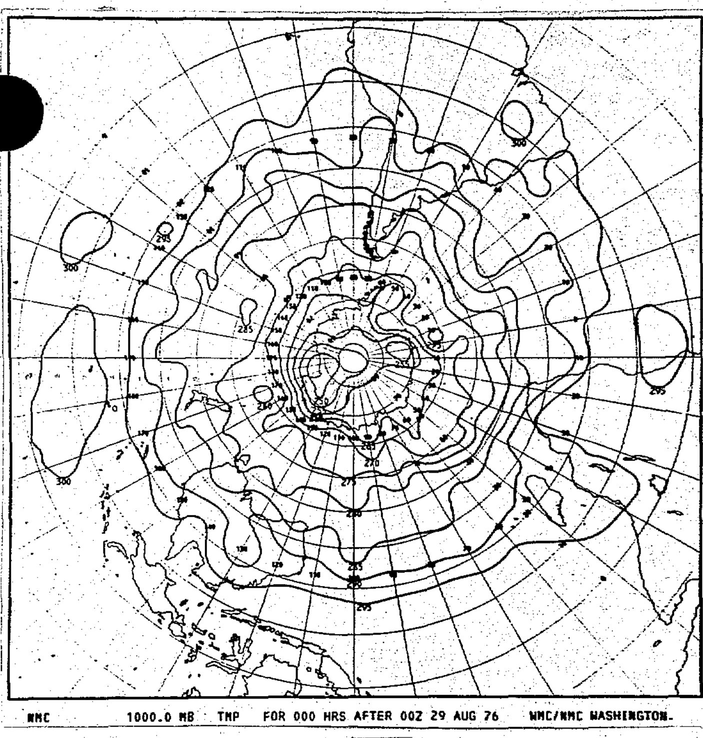
a. b.

Figure 20

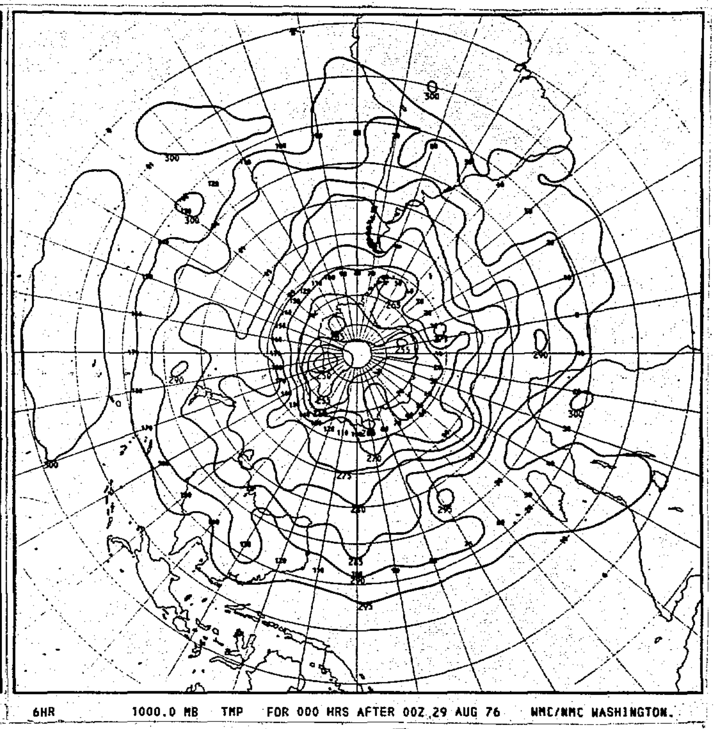
a. 12-hr cycle 1000 mb height analysis (m)
b. 6-hr cycle 1000 mb height analysis (m)
c. Forecast (first guess) differences (15 m interval)
d. Analysis differences (15 m interval)



c. d.



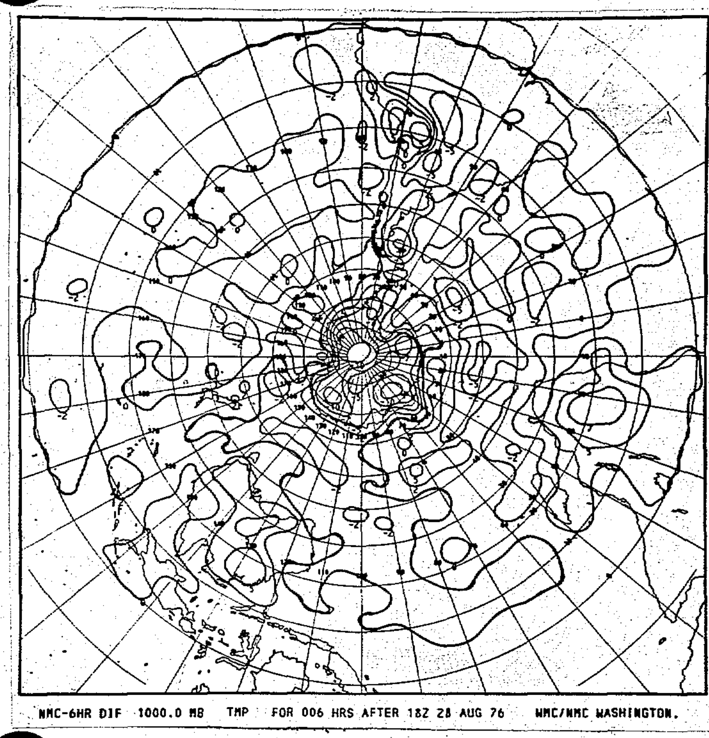
a.



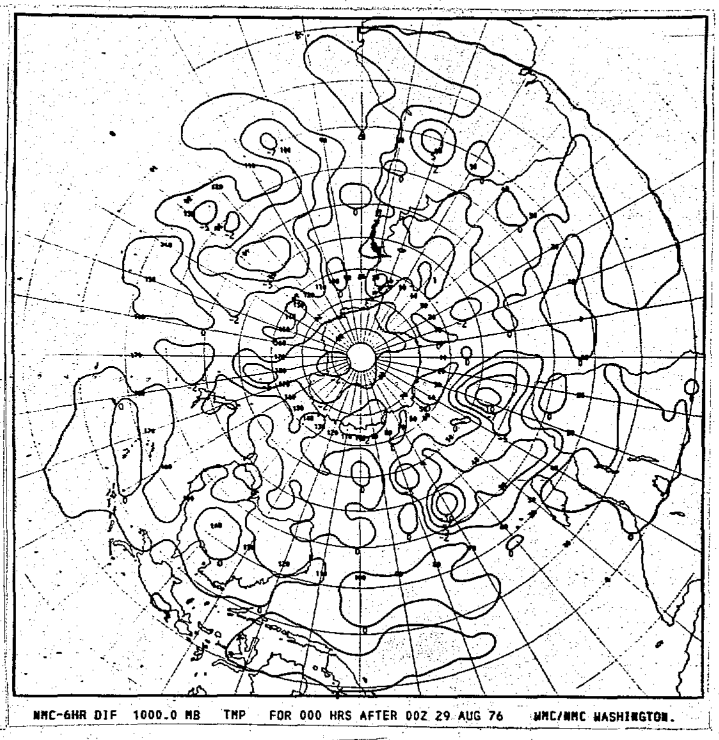
b.

Figure 21

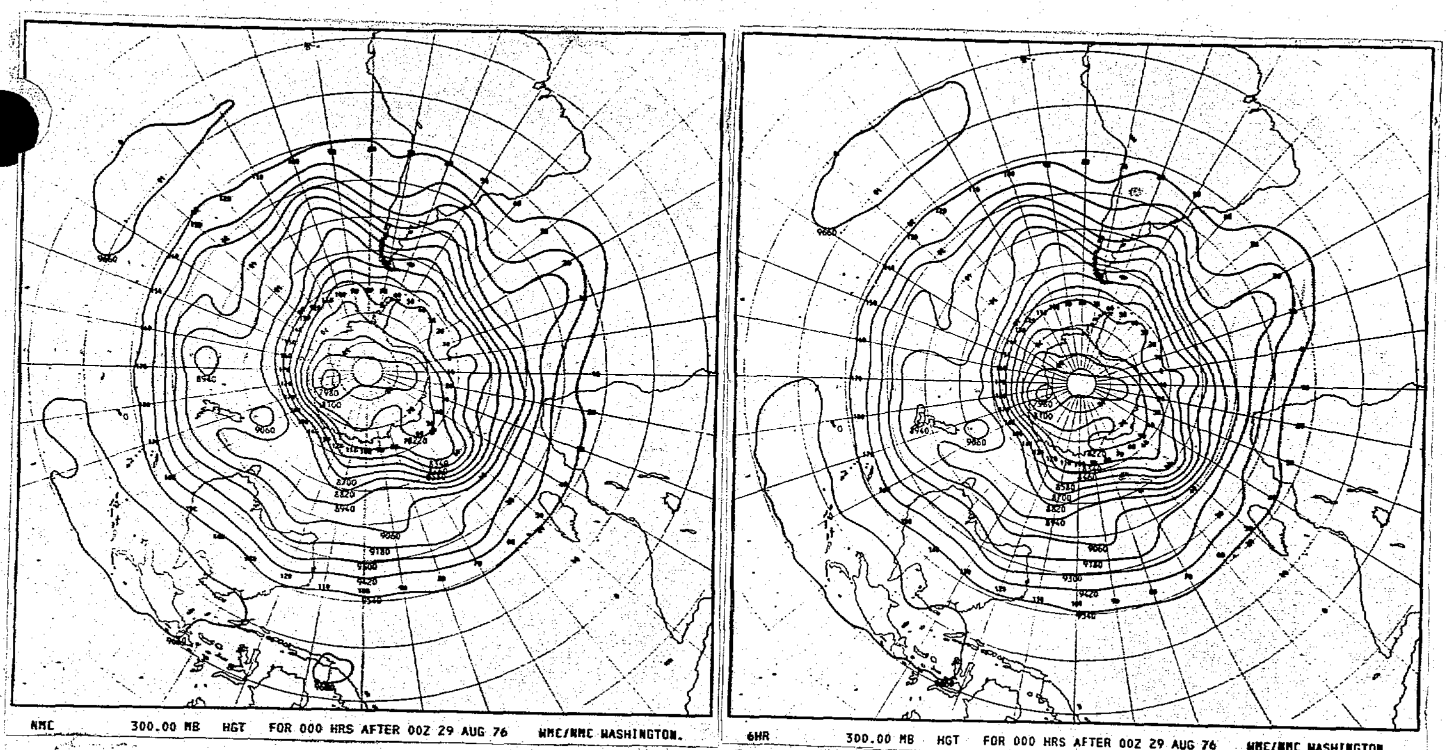
a. 12-hr cycle 1000 mb temperature analysis (°k)
b. 6-hr cycle 1000 mb temperature analysis (°k)
c. Forecast (first guess) differences (2.5°k interval)
d. Analysis differences (2.5°k interval)



c.



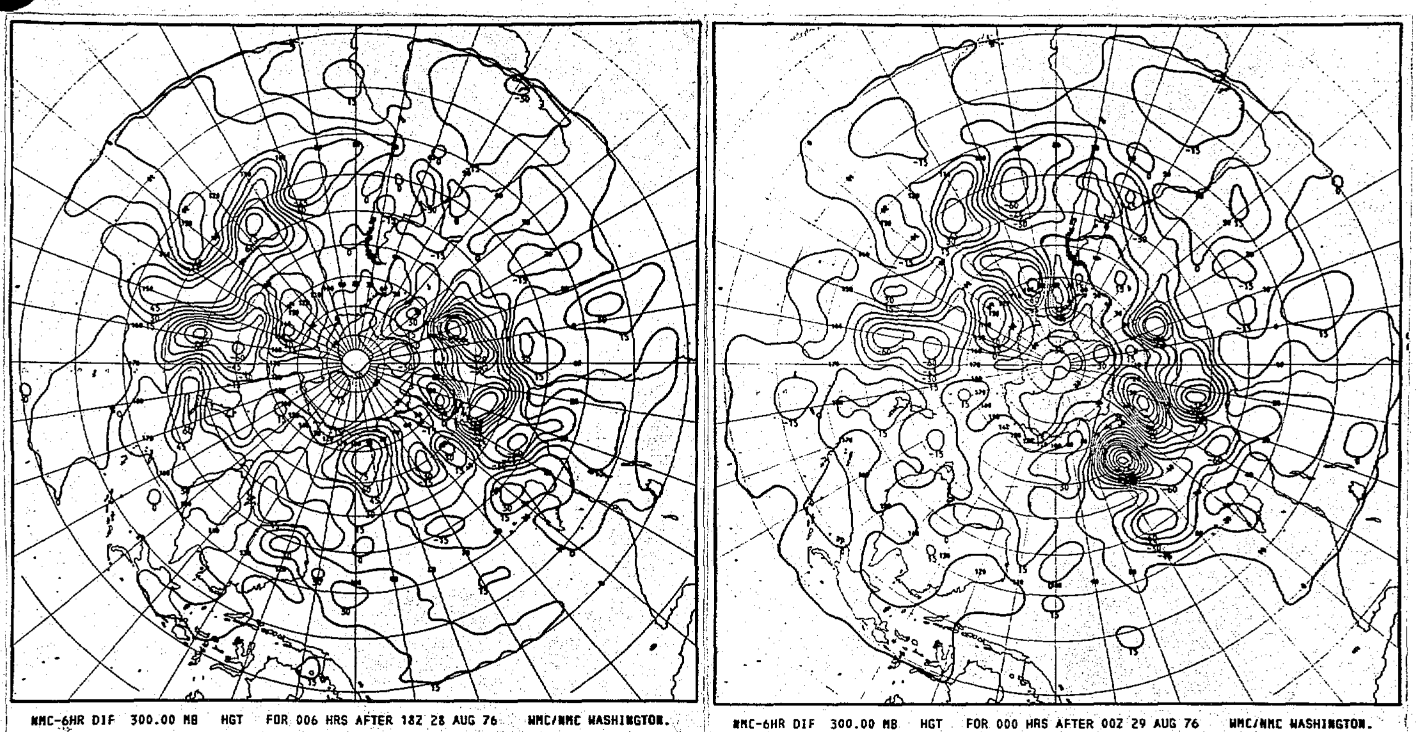
d.



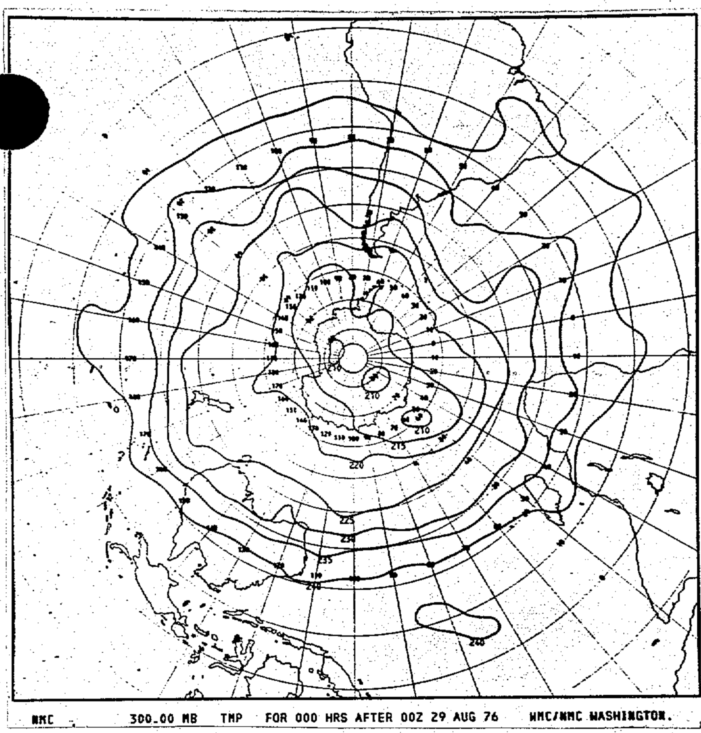
a. b.

Figure 22

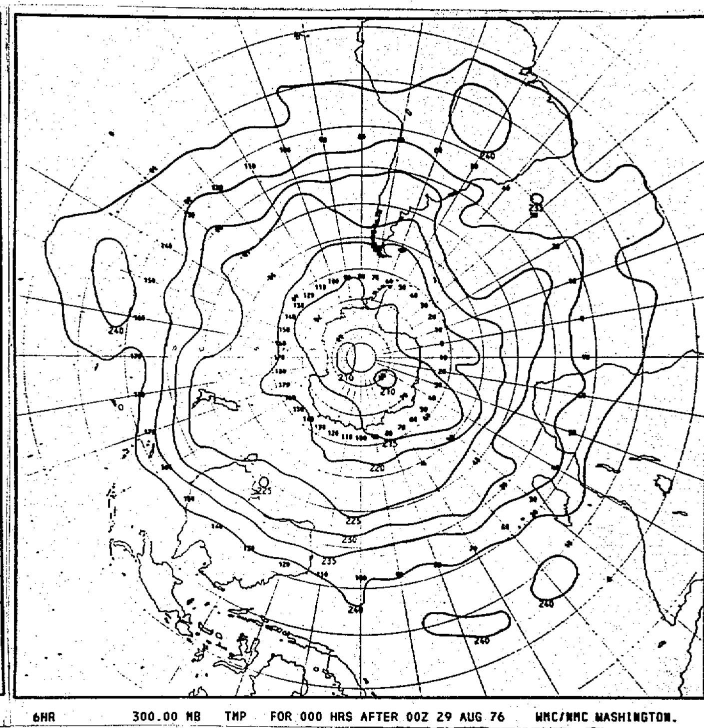
a. 12-hr cycle 300 mb height analysis (m)
b. 6-hr cycle 300 mb height analysis (m)
c. Forecast (first guess) difference (15 m interval)
d. Analysis differences (15 m interval)



c. d.



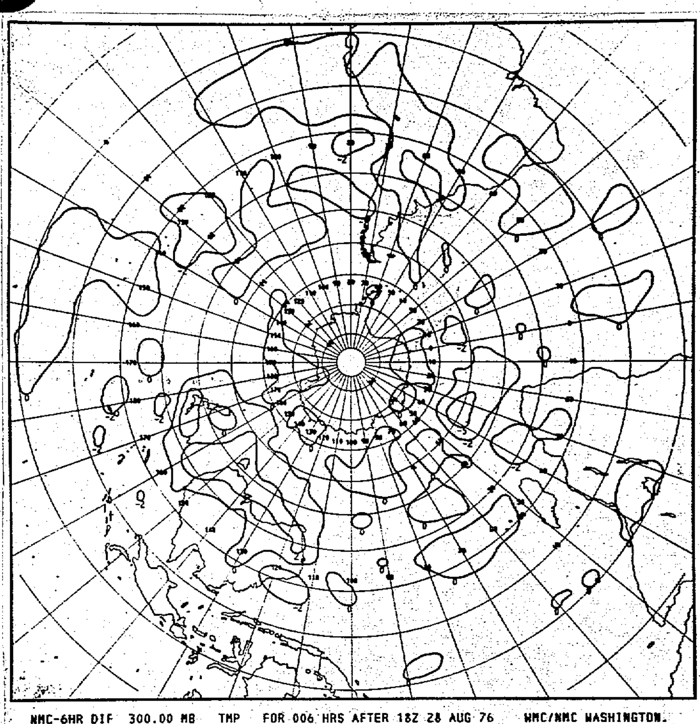
a.



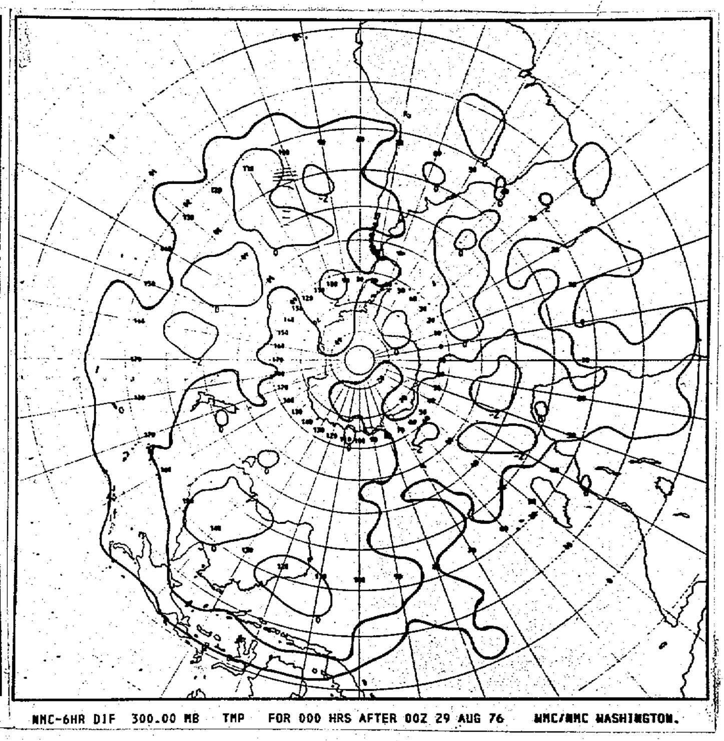
b.

Figure 23

a. 12-hr cycle 300 mb temperature analysis (°k)
b. 6-hr cycle 300 mb temperature analysis (°k)
c. Forecast (first guess) differences (2.5°k interval)
d. Analysis differences (2.5°k interval)



c.



d.

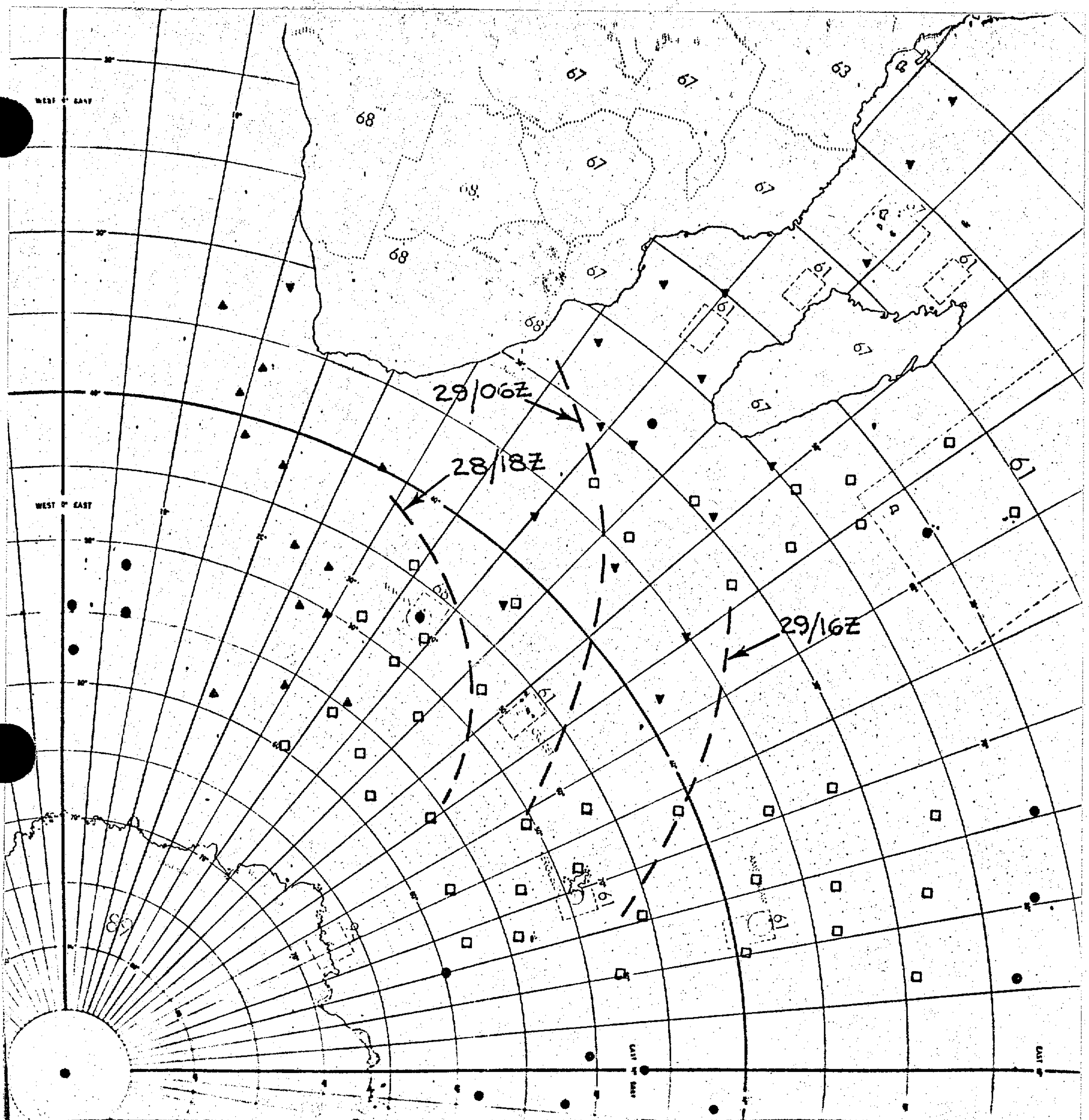


Figure 24. Upper air data coverage of the 12-hour cycle analysis, 00 GMT 29 Aug 1976. The data available to the 6-hour cycle analysis from that set are identified as:

▲	28/1801Z - 28/2100Z
●	28/2101Z - 29/0300Z
□	29/0301Z - 29/0600Z

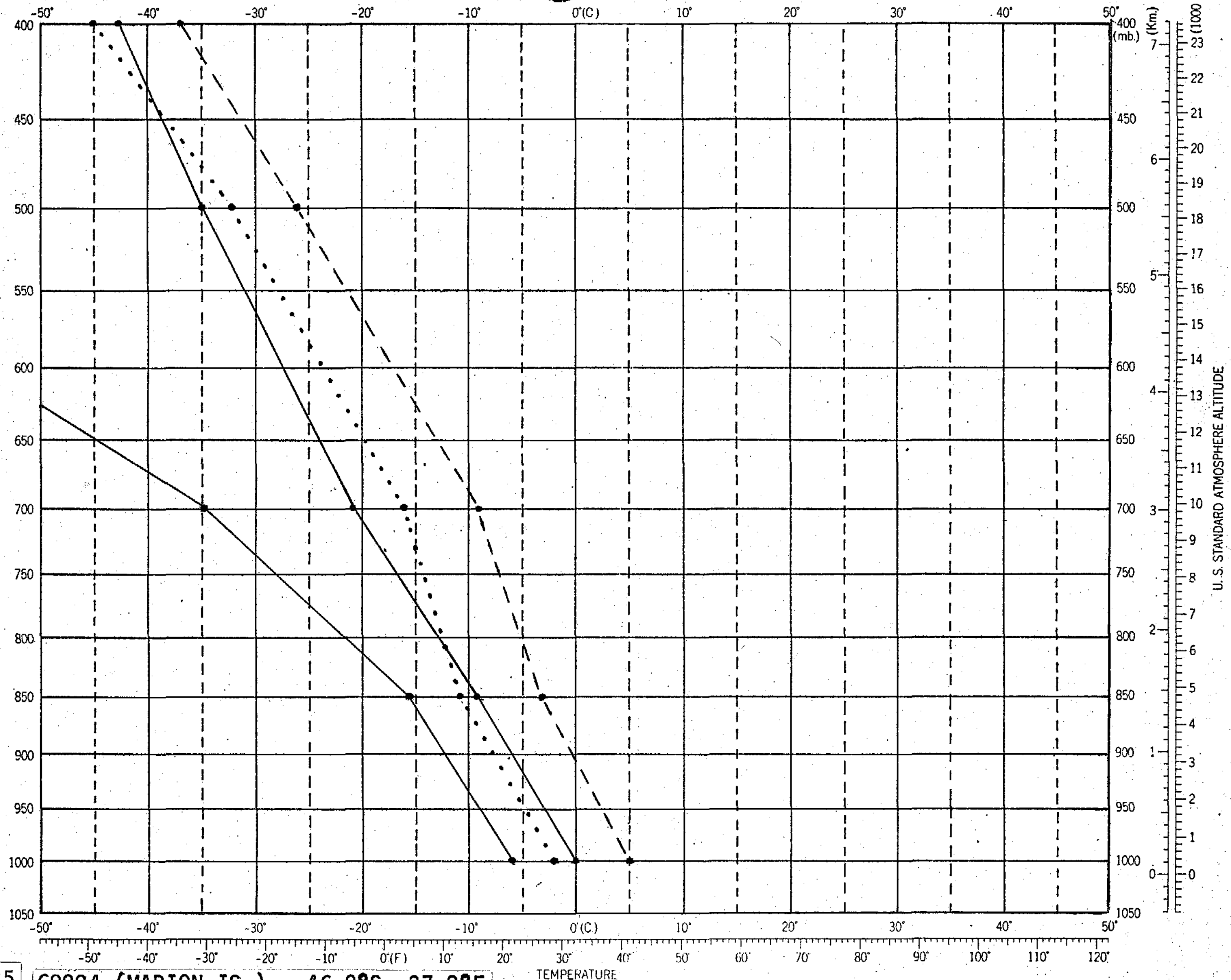
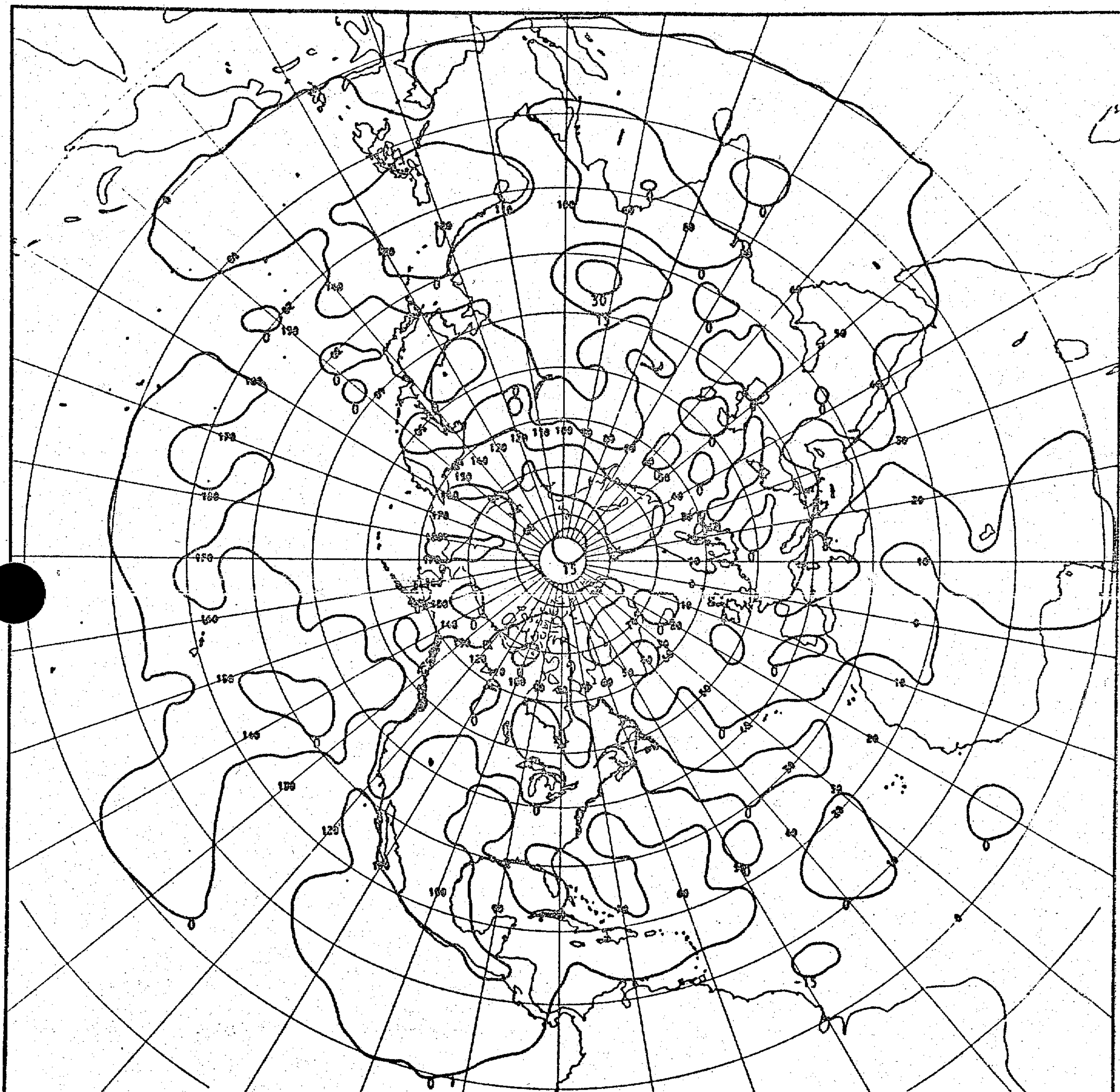


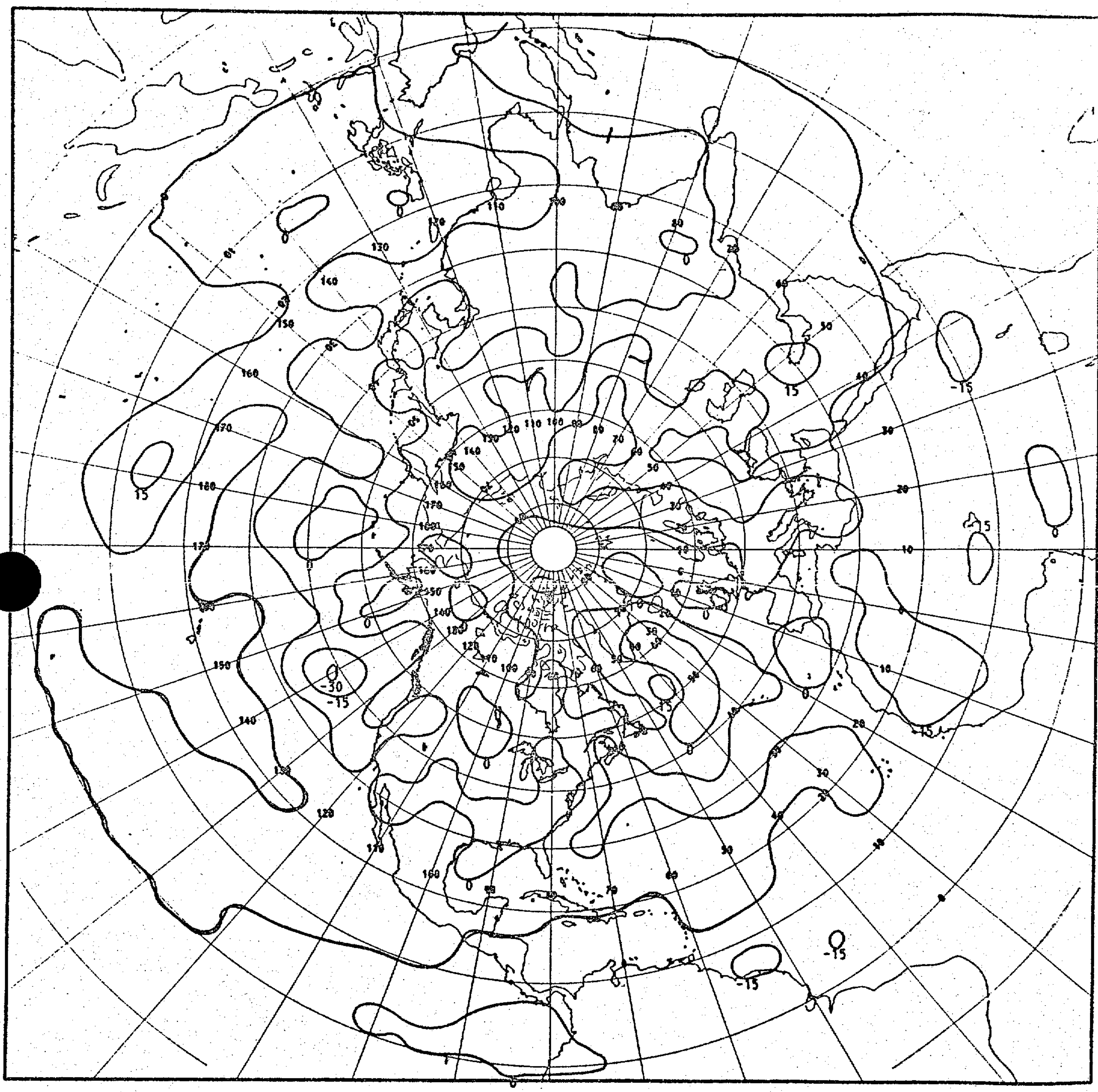
Figure 25

68994 (MARION IS.) 46.9°S 37.9°E
00Z 29 AUG 76
· · · · · · · VTPR 05Z 47.5°S 39.1°E
— — — VTPR 18Z 42.6°S 42.9°E



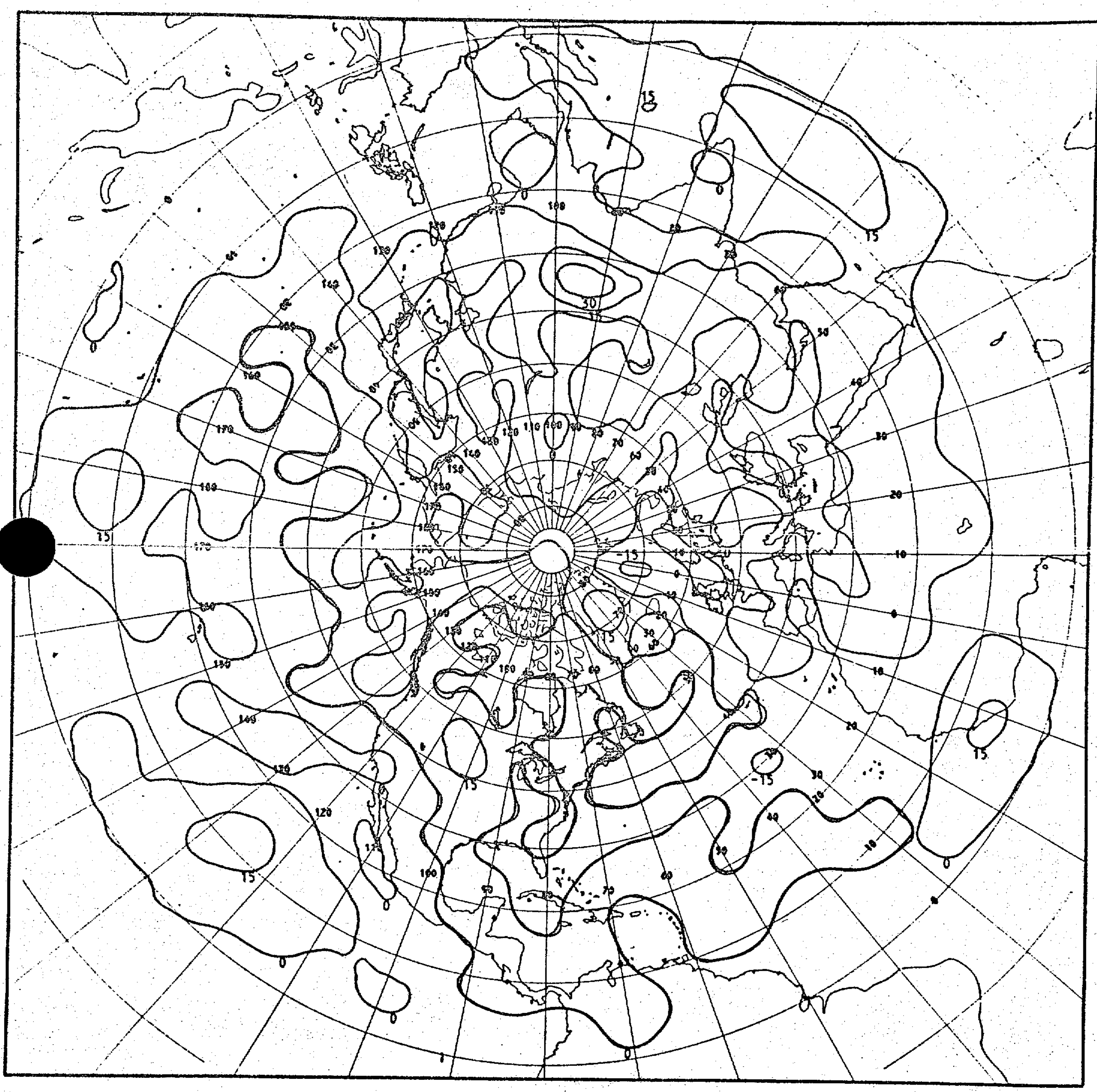
NMC-6HR DIF 1000.0 MB HGT FOR 000 HRS AFTER 00Z 28 AUG 76 WMC/NMC WASHINGTON.

Figure 26



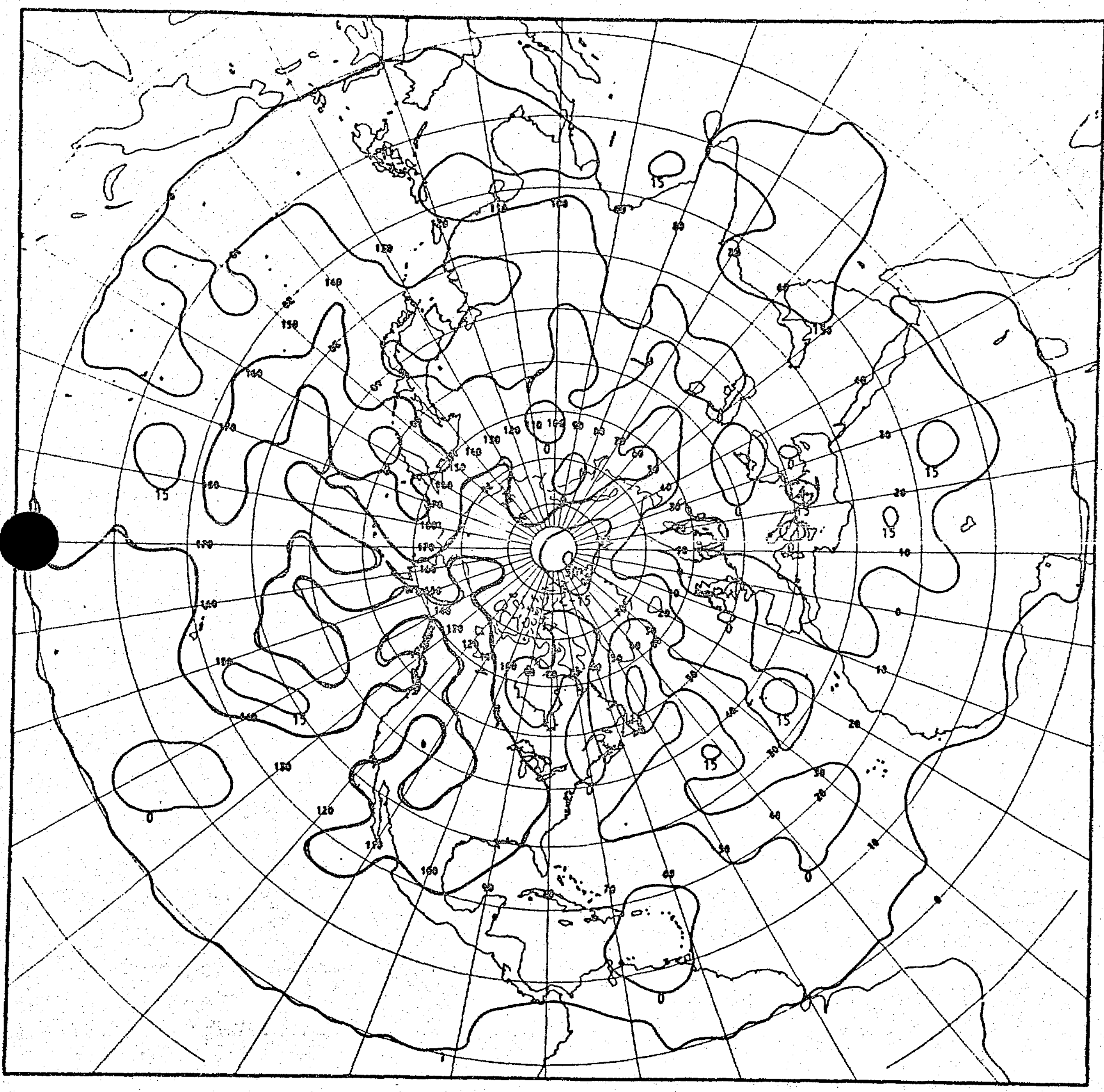
NMC-6HR DIF 300.00 MB HGT FOR 000 HRS AFTER 00Z 28 AUG 76 WMC/NMC WASHINGTON.

Figure 27



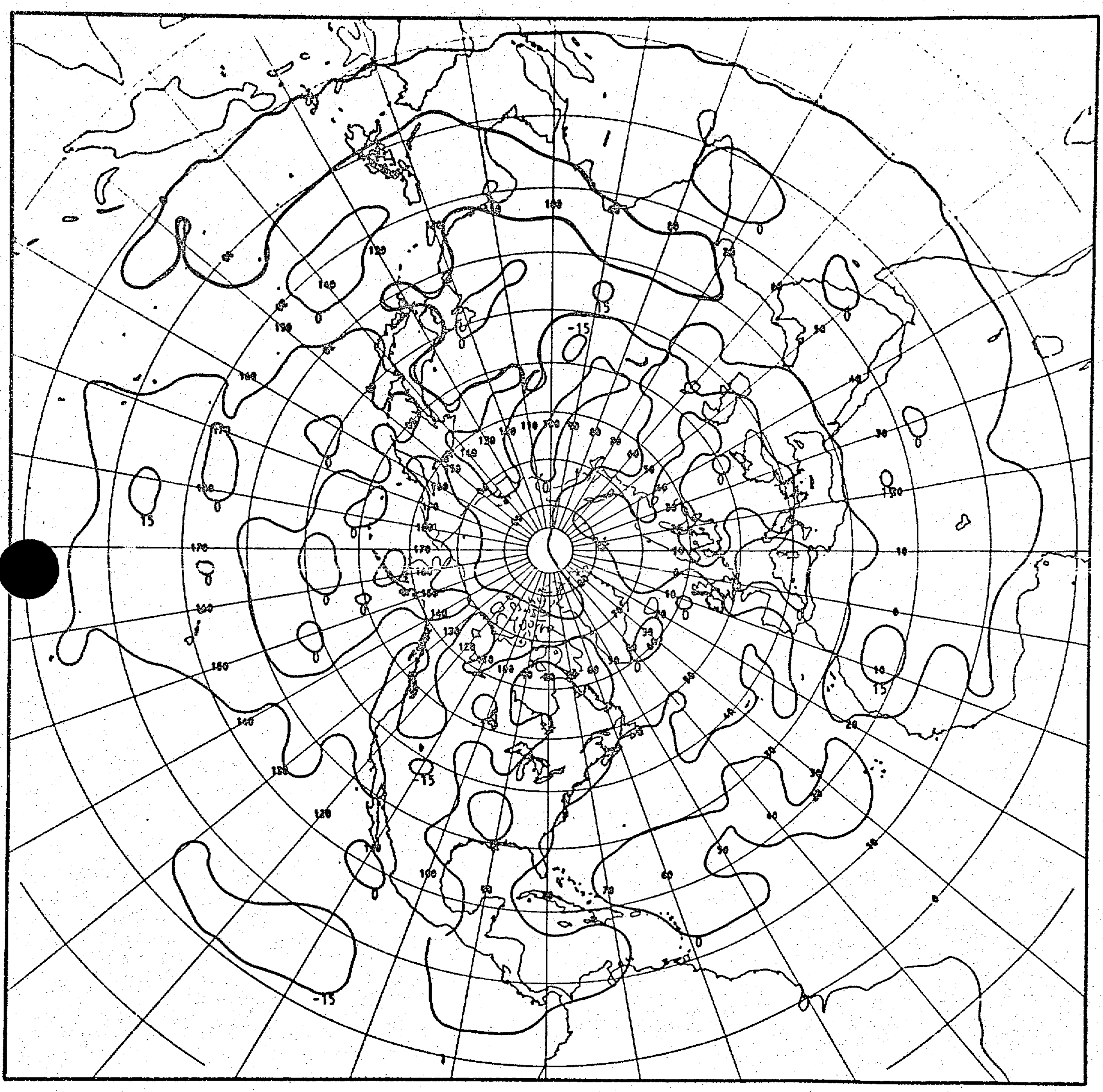
NMC-6HR DIF 1000.0 MB HGT FOR 000 HRS AFTER 00Z 30 AUG 76 WMC/NMC WASHINGTON.

Figure 28



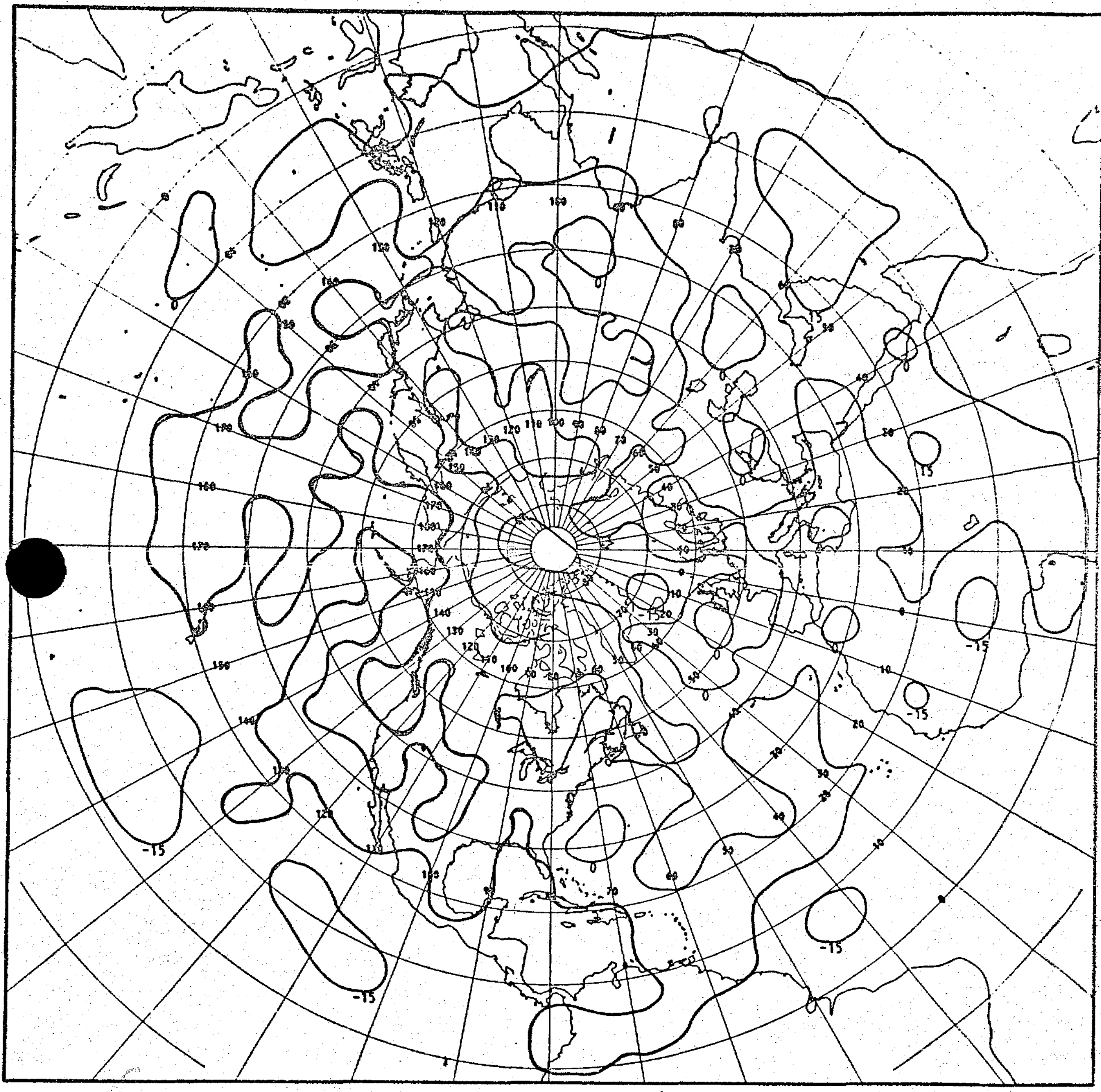
NMC-6HR DIF 300.00 MB HGT FOR 000 HRS AFTER 00Z 30 AUG 76 WMC/NMC WASHINGTON.

Figure 29



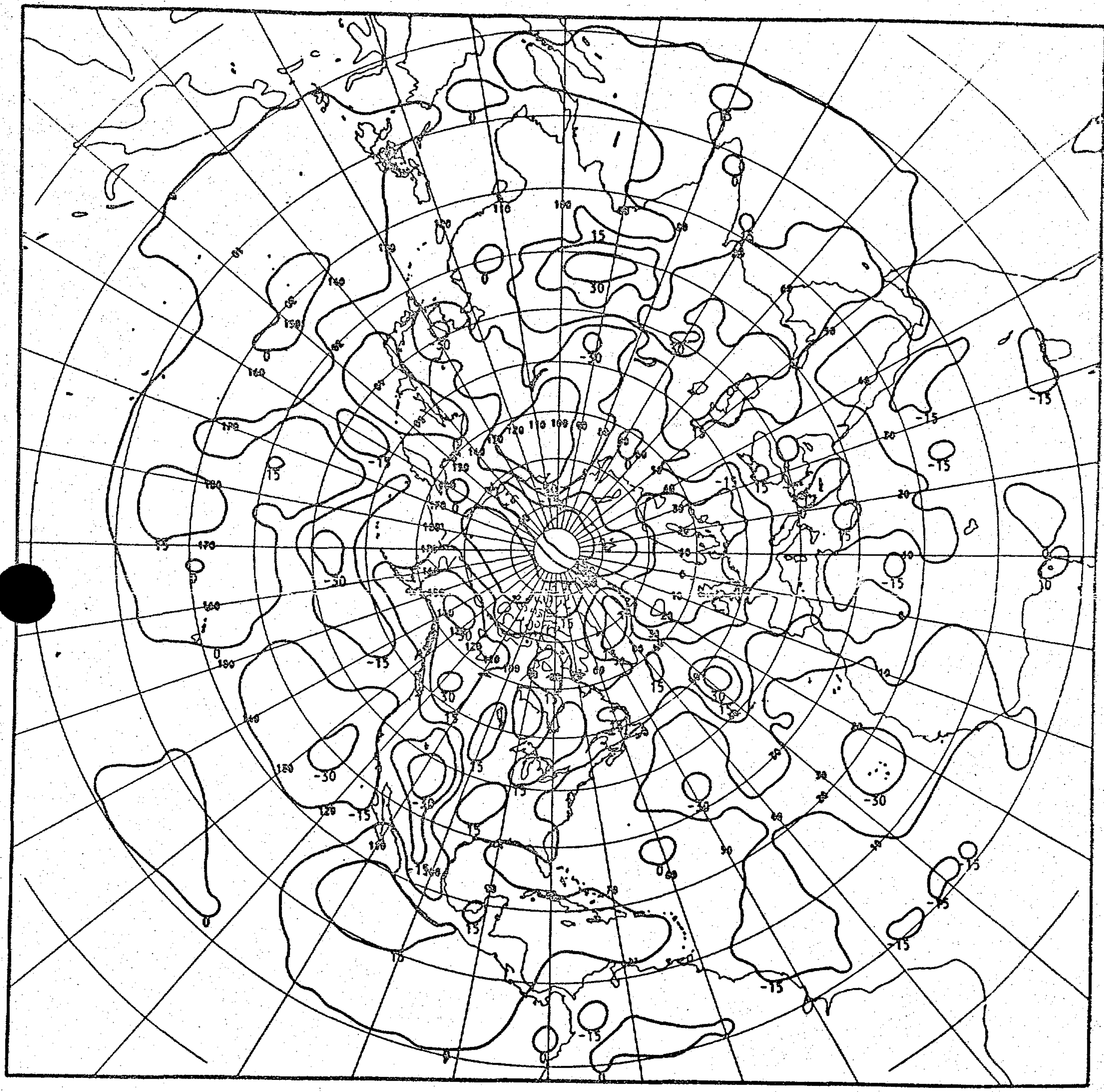
NMC-6HR DIF 1000.0 MB HGT FOR 000 HRS AFTER 00Z 1 SEP 76 WMC/NMC WASHINGTON.

Figure 30



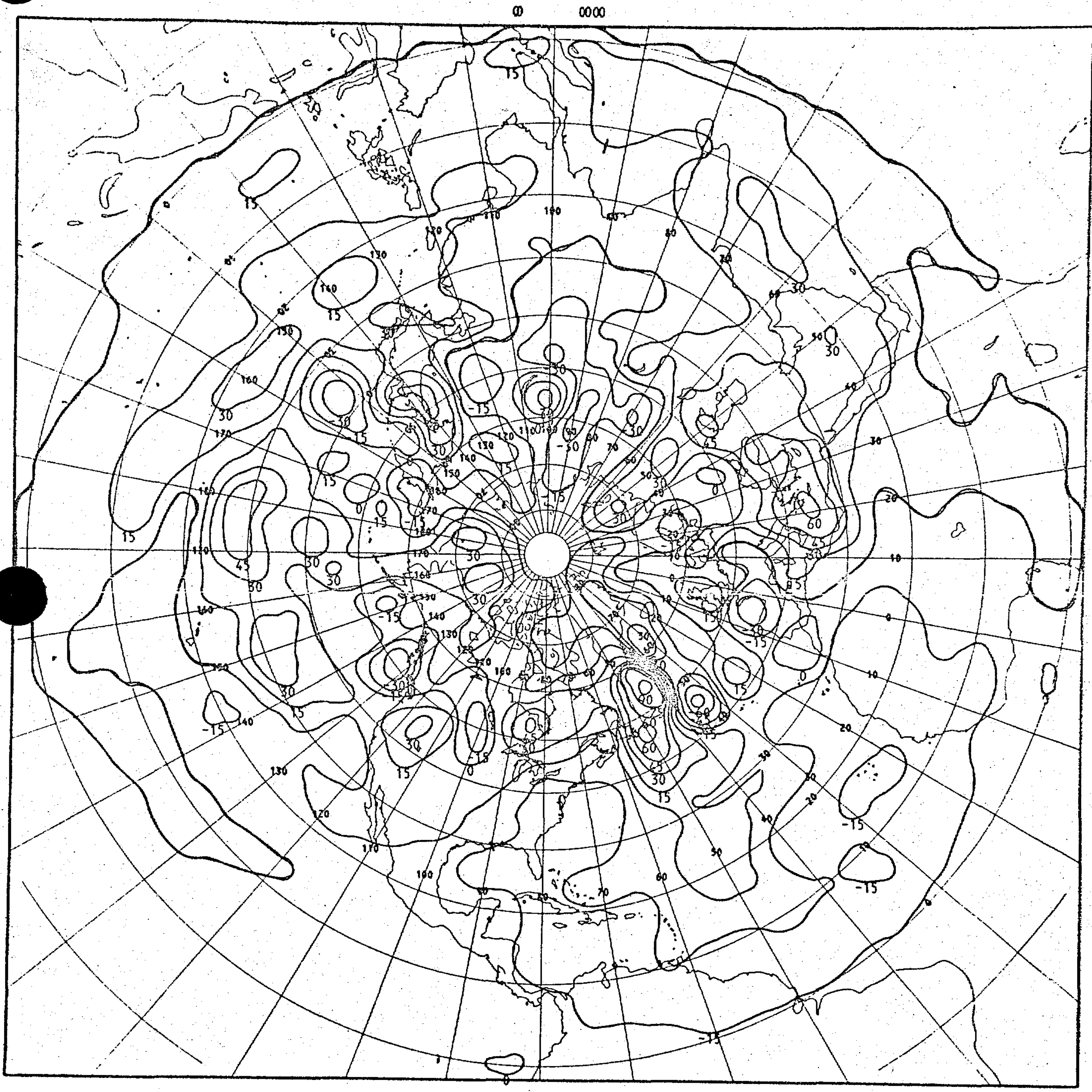
NMC-6HR DIF 300.00 MB HGT FOR 000 HRS AFTER 00Z 1 SEP 76 WMC/NMC WASHINGTON.

Figure 31



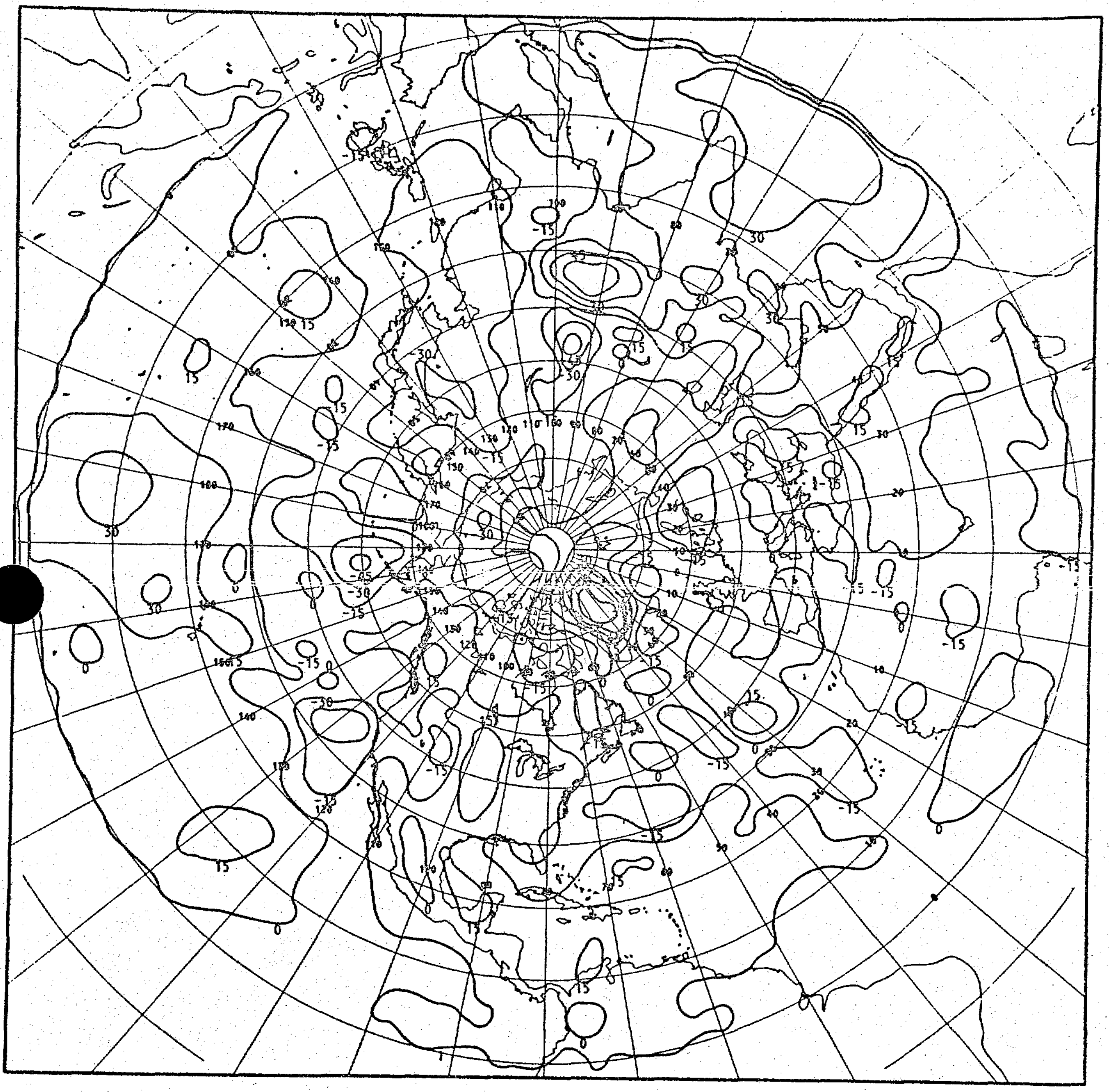
NMC-6HR DIF 1000.0 MB HGT FOR 006 HRS AFTER 18Z 27 AUG 76 WMC/NMC WASHINGTON.

Figure 32



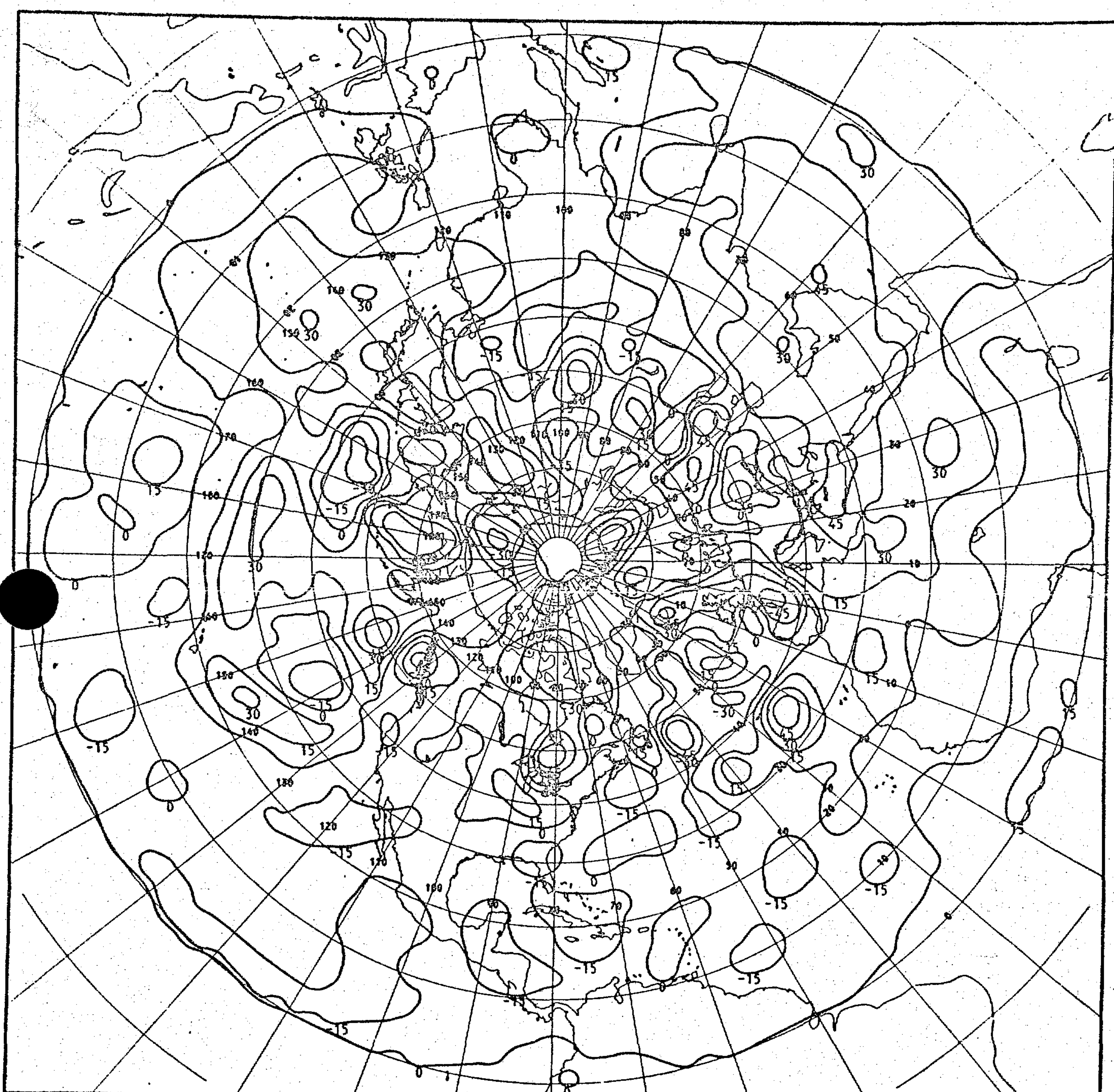
NMC-6HR DIF 300.00 MB HGT FOR 006 HRS AFTER 18Z 27 AUG 76 WMC/NMC WASHINGTON.

Figure 33



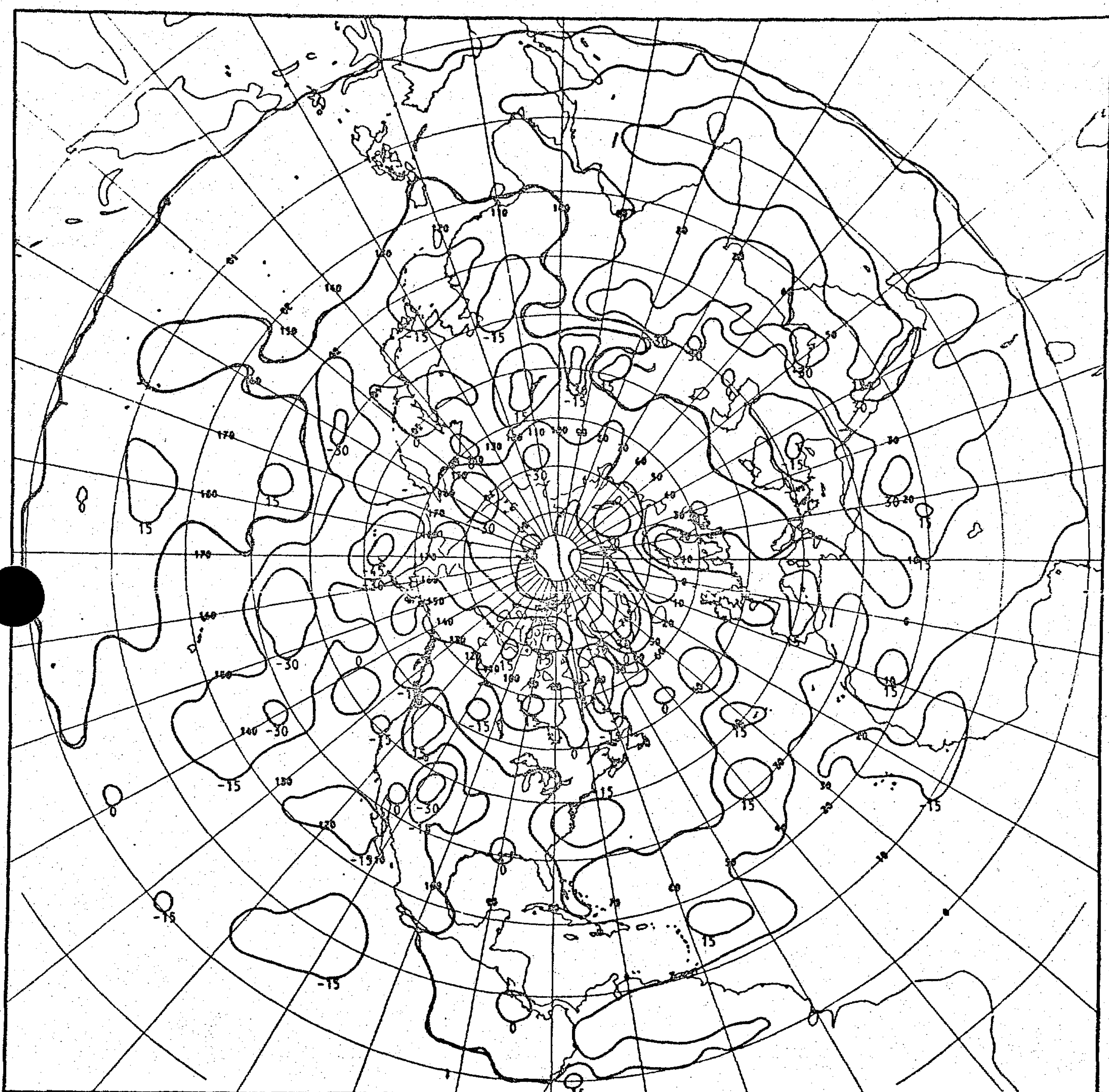
NMC-6HR DIF 1000.0 MB HGT FOR 006 HRS AFTER 18Z 29 AUG 76 WMC/NMC WASHINGTON.

Figure 34



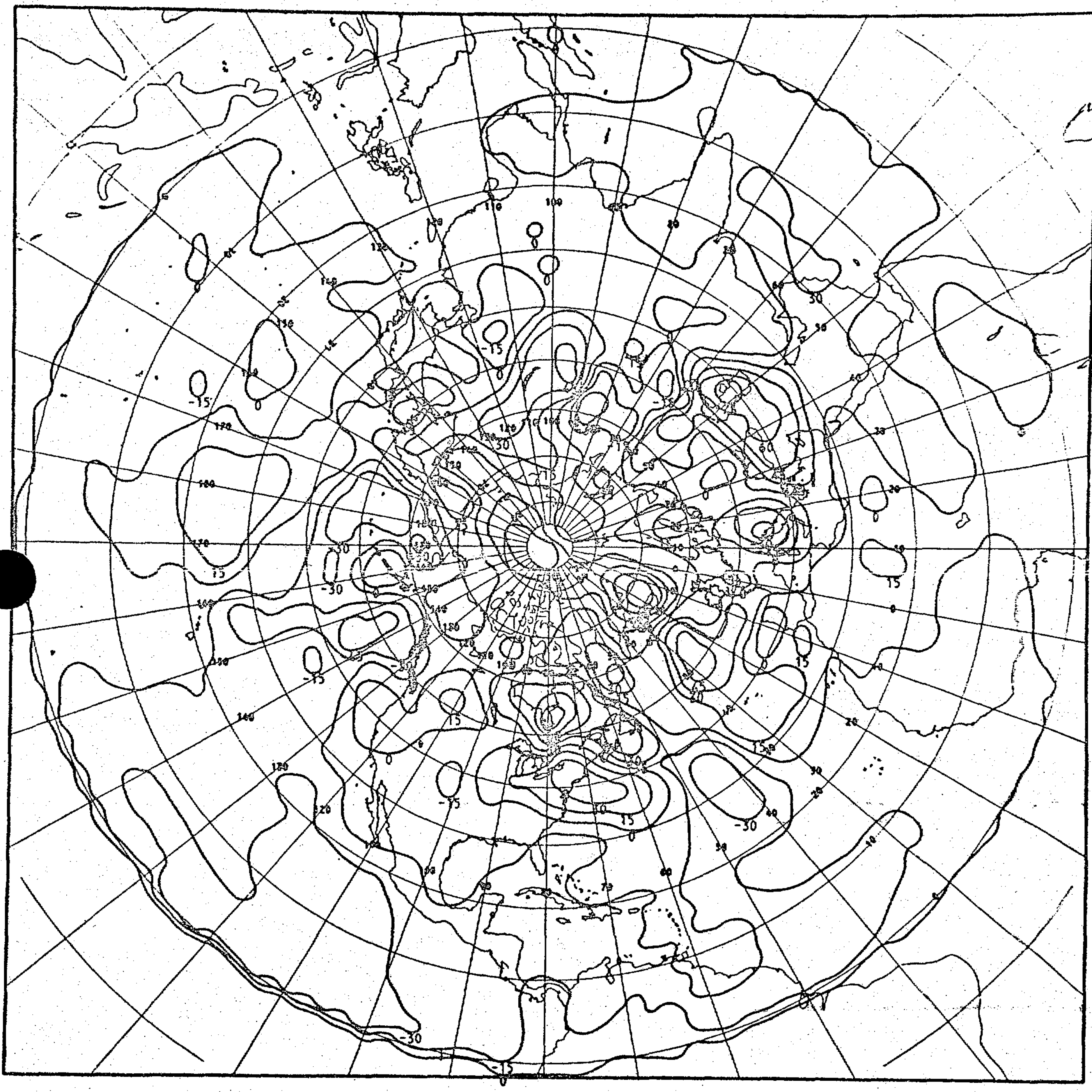
NMC-6HR DIF 300.00 MB HGT FOR 006 HRS AFTER 18Z 29 AUG 76 WMC/NMC WASHINGTON.

Figure 35



NMC-6HR DIF 1000.0 MB HGT FOR 006 HRS AFTER 18Z 31 AUG 76 WMC/NMC WASHINGTON.

Figure 36



NMC-6HR DIF 300.00 MB HGT FOR 006 HRS AFTER 18Z 31 AUG 76 WMC/NMC WASHINGTON.

Figure 37

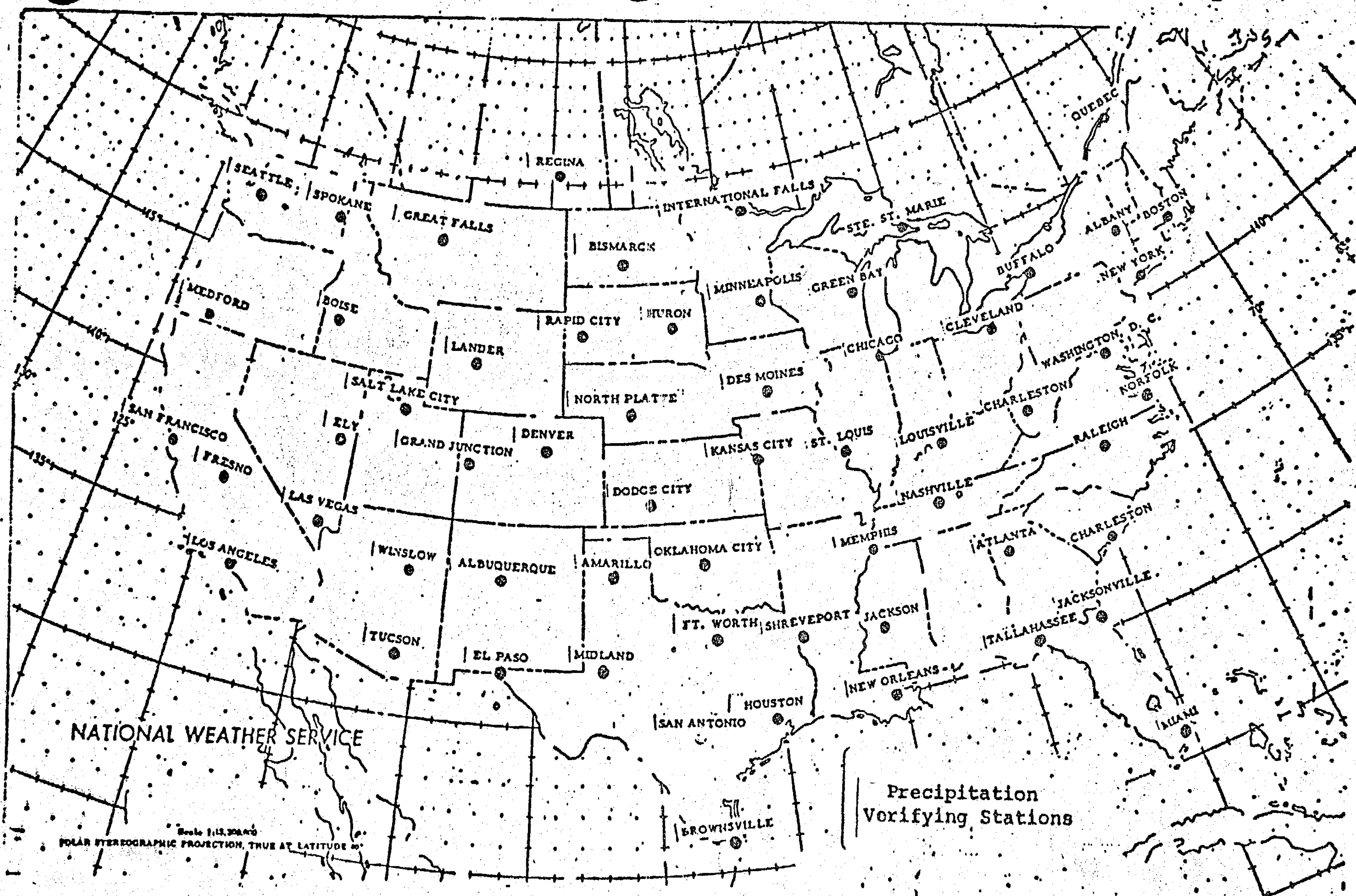

SEATTLE
SPOKANE
GREAT FALLS
REGINA
INTERNATIONAL FALLS
STE. ST. MARIE
QUEBEC
ALBANY
BOSTON
BISMARCK
MINNEAPOLIS
GREEN BAY
BUFFALO
NEW YORK
MEDFORD
BOISE
RAPID CITY
HURON
CLEVELAND
LANDER
CHICAGO
WASHINGTON, D. C.
SALT LAKE CITY
NORTH PLATTE
DES MOINES
NORFOLK
CHARLESTON
SAN FRANCISCO
ELY
GRAND JUNCTION
DENVER
KANSAS CITY
ST. LOUIS
LOUISVILLE
RALEIGH
FRESNO
DODGE CITY
NASHVILLE
LAS VEGAS
MEMPHIS
ATLANTA
CHARLESTON
LOS ANGELES
WINSLOW
ALBUQUERQUE
AMARILLO
OKLAHOMA CITY
JACKSONVILLE
FT. WORTH
SHREVEPORT
JACKSON
TALLAHASSEE
TUCSON
EL PASO
MIDLAND
NEW ORLEANS
HOUSTON
SAN ANTONIO
MIAMI
NATIONAL WEATHER SERVICE
BROWNSVILLE
POLAR STEREOGRAPHIC PROJECTION, TRUE AT LATITUDE 60°
Precipitation
Verifying Stations

Figure 38

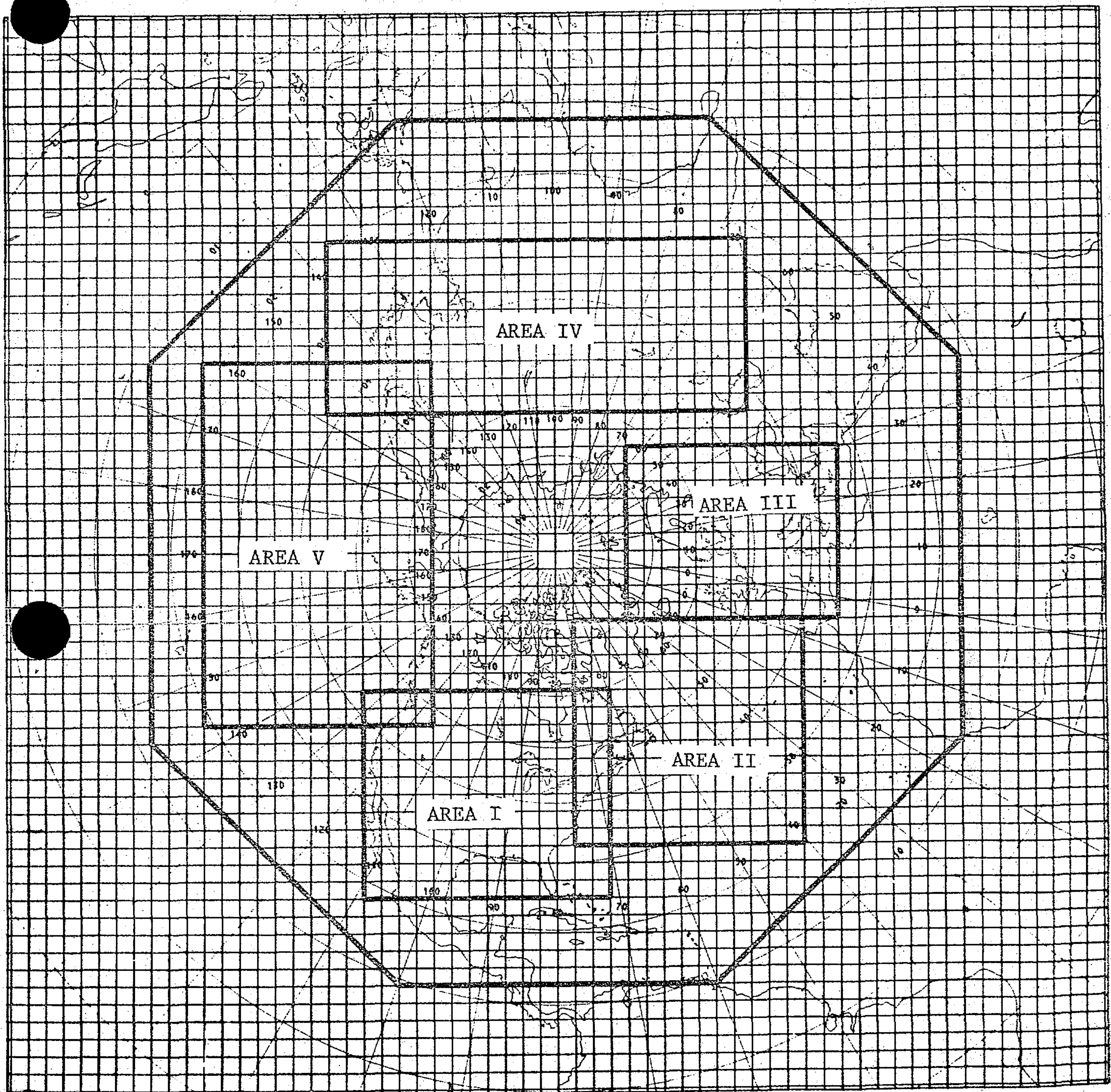
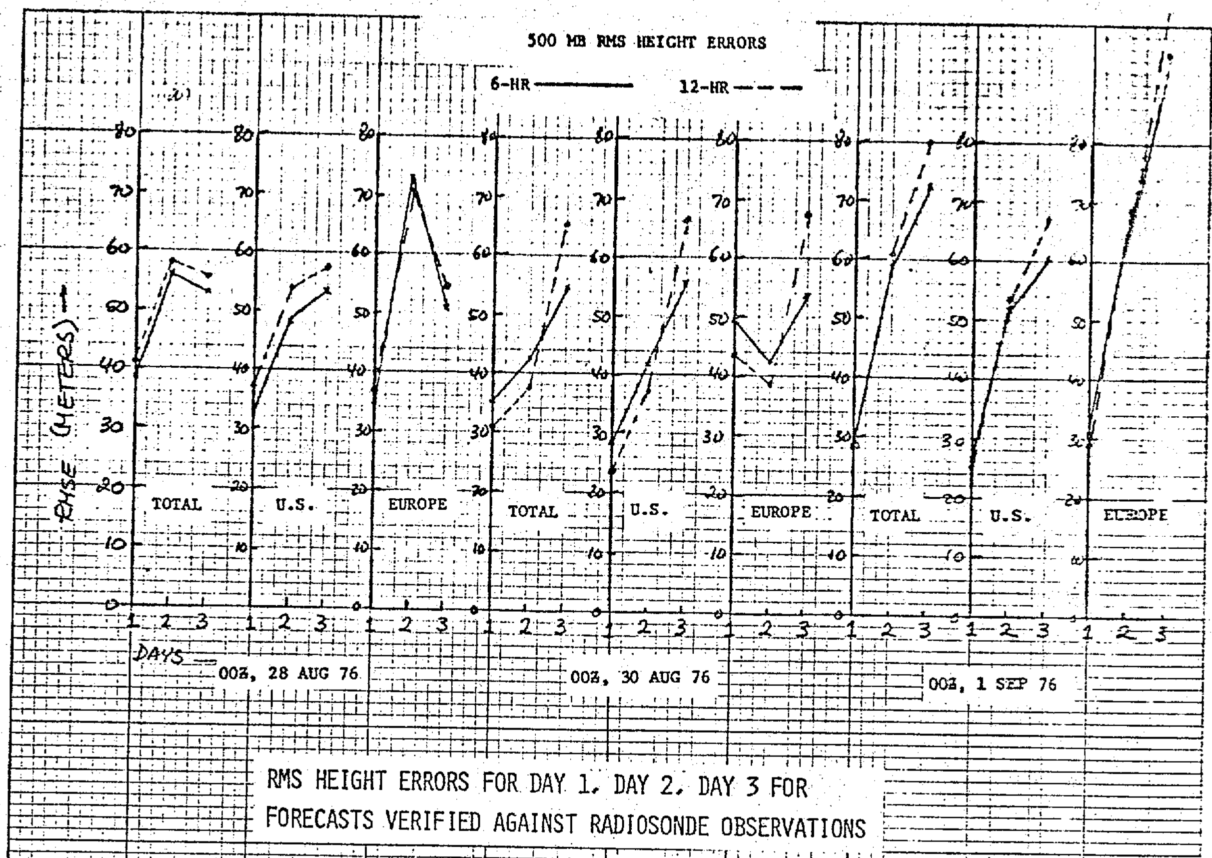
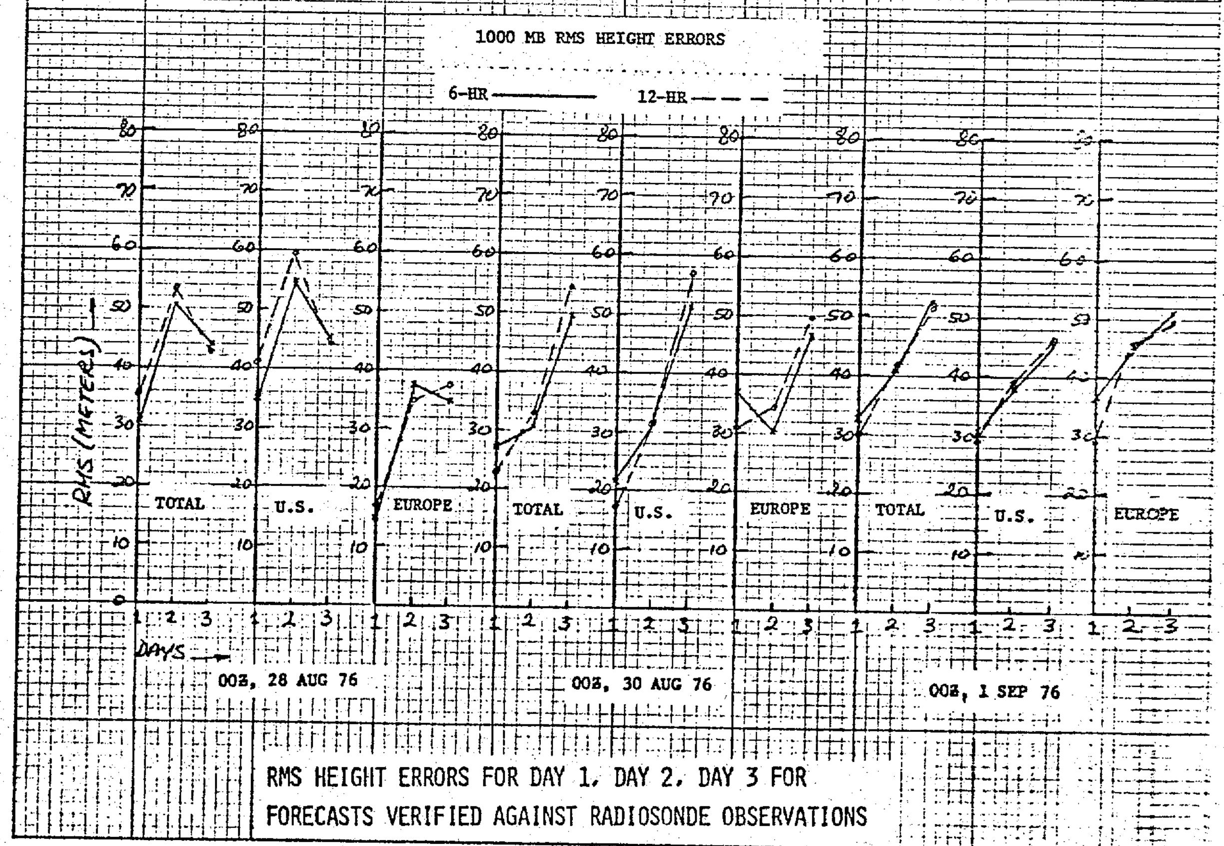


Figure 39



500 MB RMS HEIGHT ERRORS
6-HR
12-HR
RMSE (METERS)
TOTAL
U.S.
EUROPE
DAYS
00Z, 28 AUG 76
00Z, 30 AUG 76
00Z, 1 SEP 76
RMS HEIGHT ERRORS FOR DAY 1, DAY 2, DAY 3 FOR
FORECASTS VERIFIED AGAINST RADIOSONDE OBSERVATIONS



1000 MB RMS HEIGHT ERRORS
6-HR
12-HR
RMS (METERS)
TOTAL
U.S.
EUROPE
DAYS
00Z, 28 AUG 76
00Z, 30 AUG 76
00Z, 1 SEP 76
RMS HEIGHT ERRORS FOR DAY 1, DAY 2, DAY 3 FOR
FORECASTS VERIFIED AGAINST RADIOSONDE OBSERVATIONS

Figure 40a

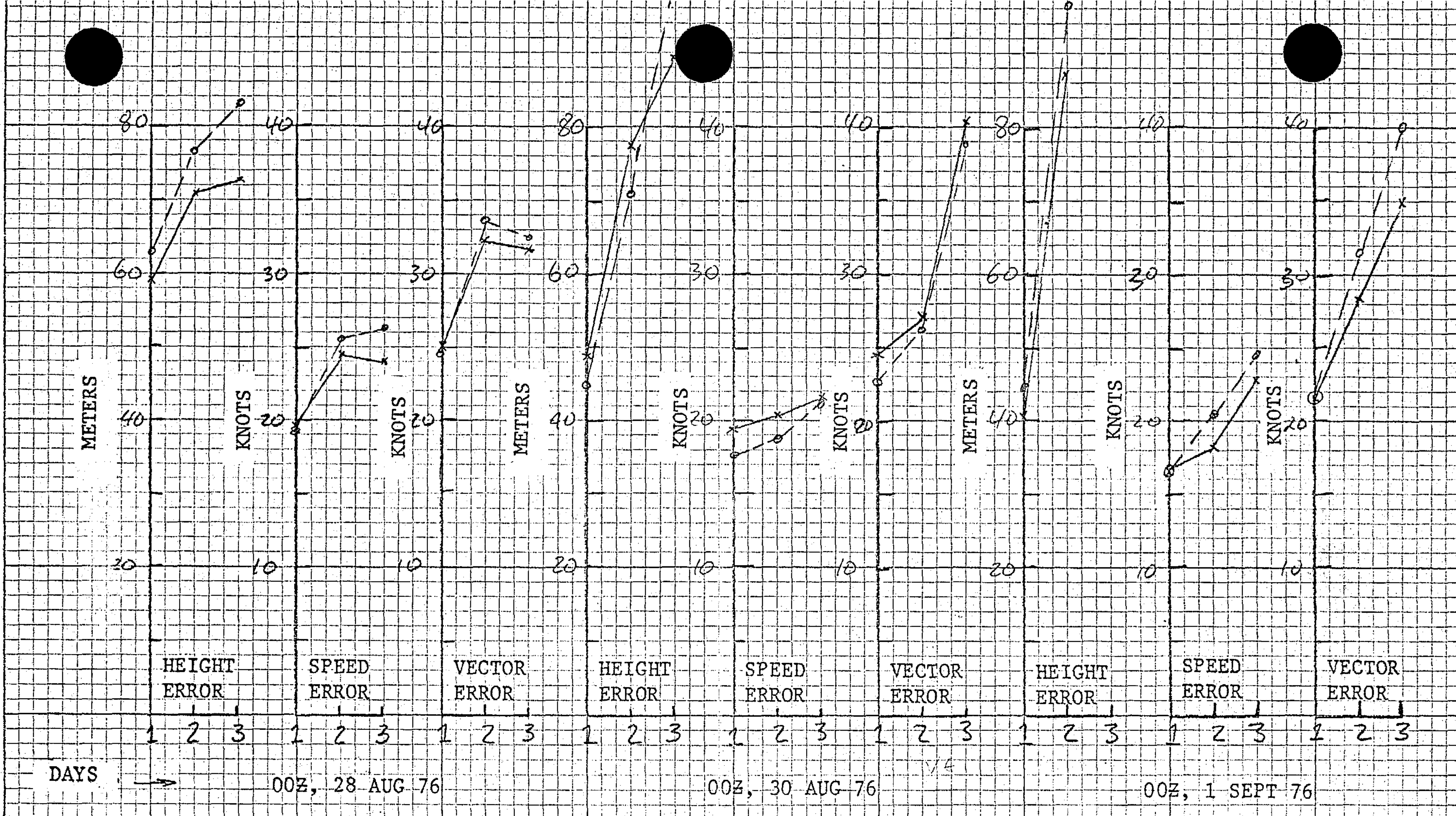
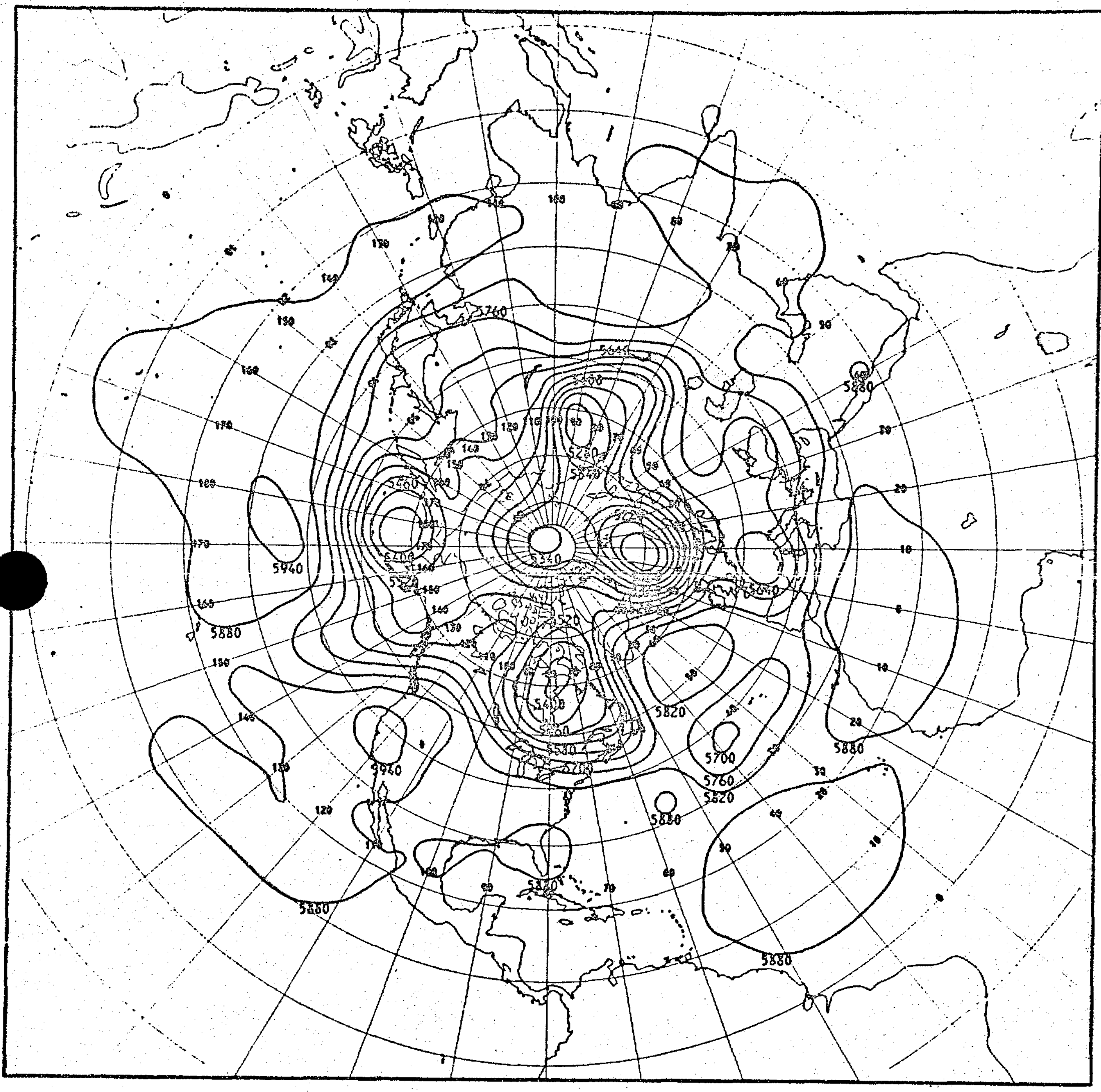


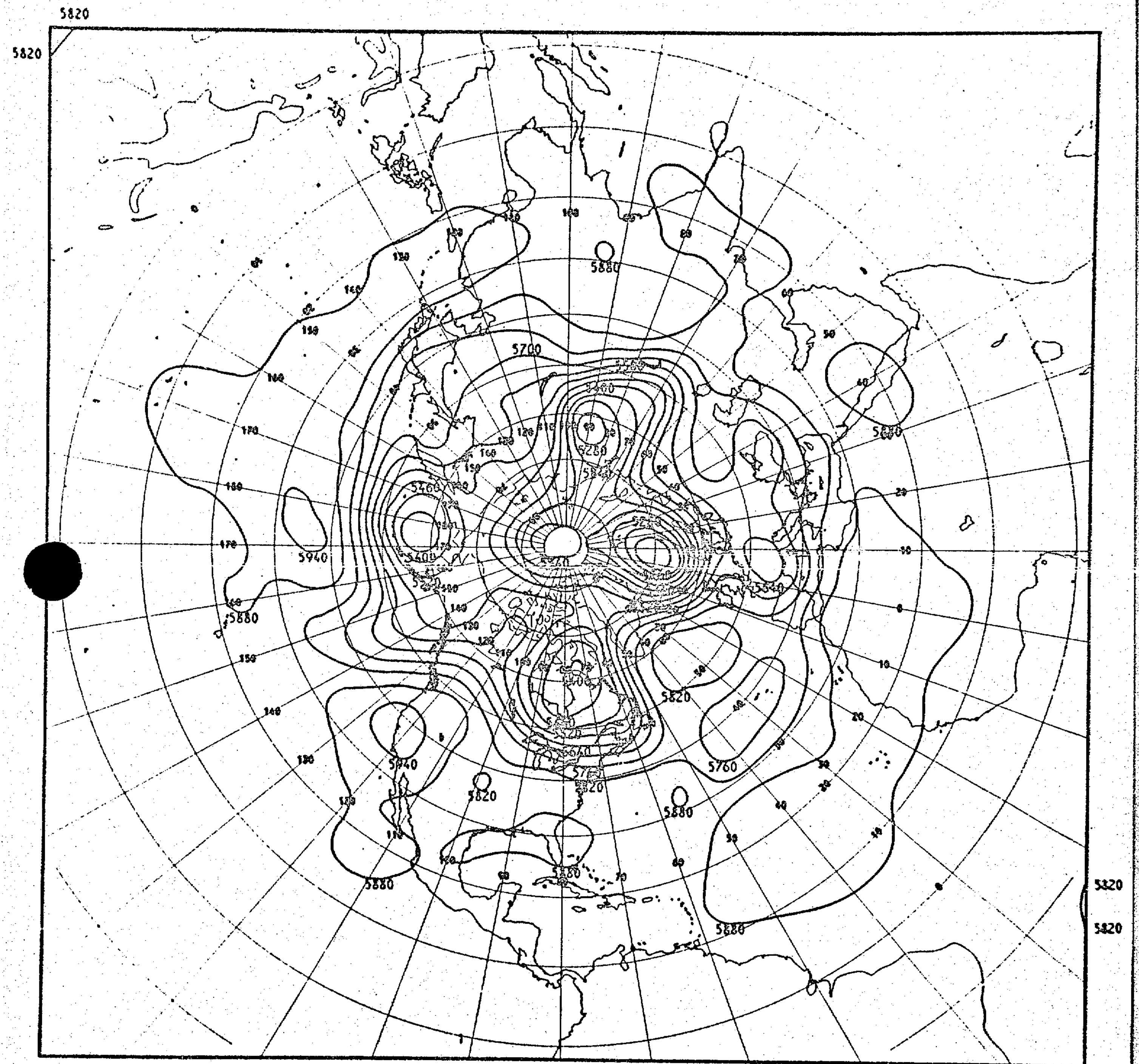
Figure 40b

300 MB RMS HEIGHT, SPEED AND VECTOR ERRORS FOR FORECASTS VERIFIED AGAINST OBSERVATIONS (75 RADIOSONDE STATIONS OVER EASTERN PACIFIC, UNITED STATES, ATLANTIC AND EUROPE)



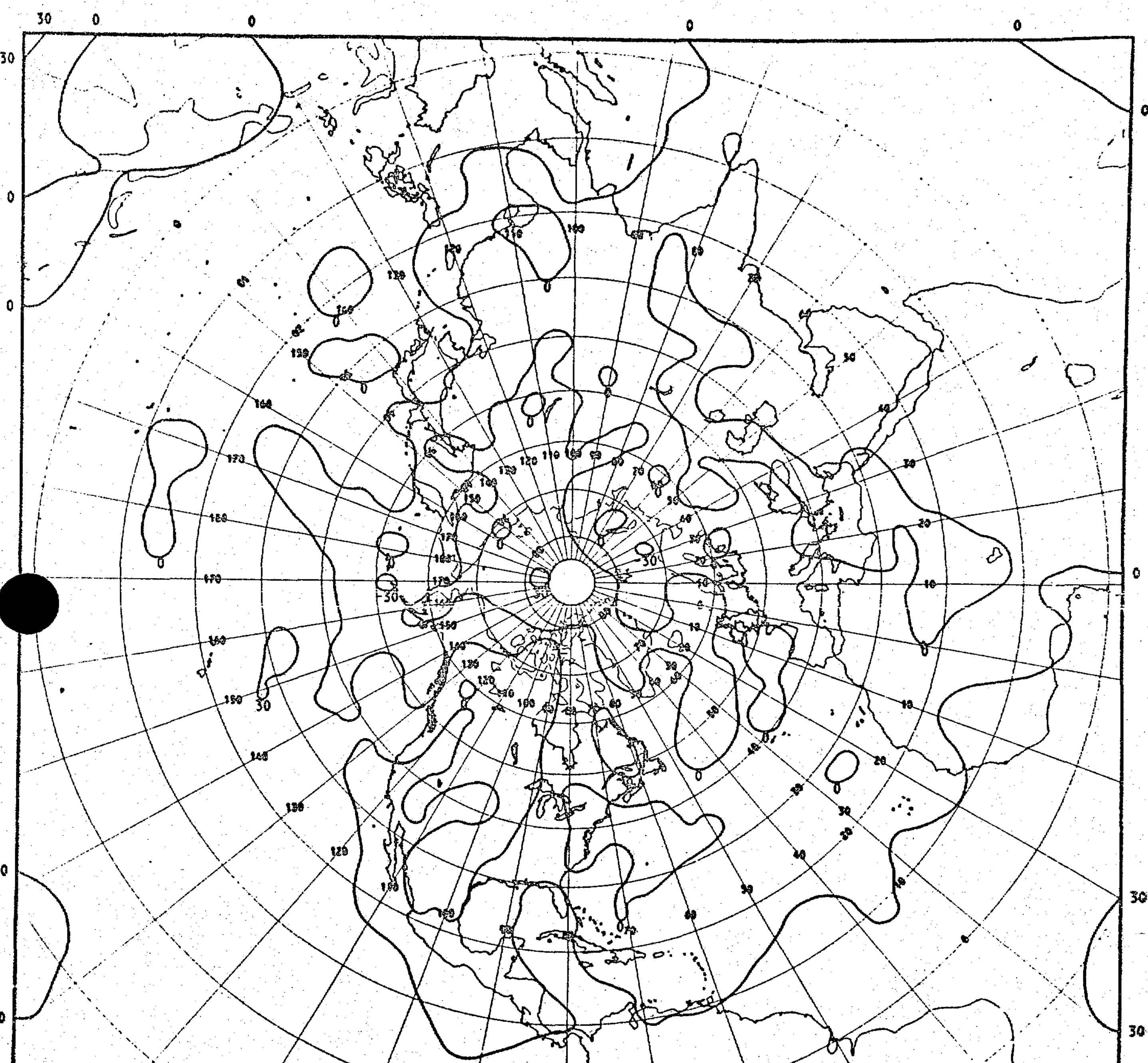
500.00 MB HGT FOR 000 HRS AFTER 00Z 1 SEP 76 06HR

Figure 41



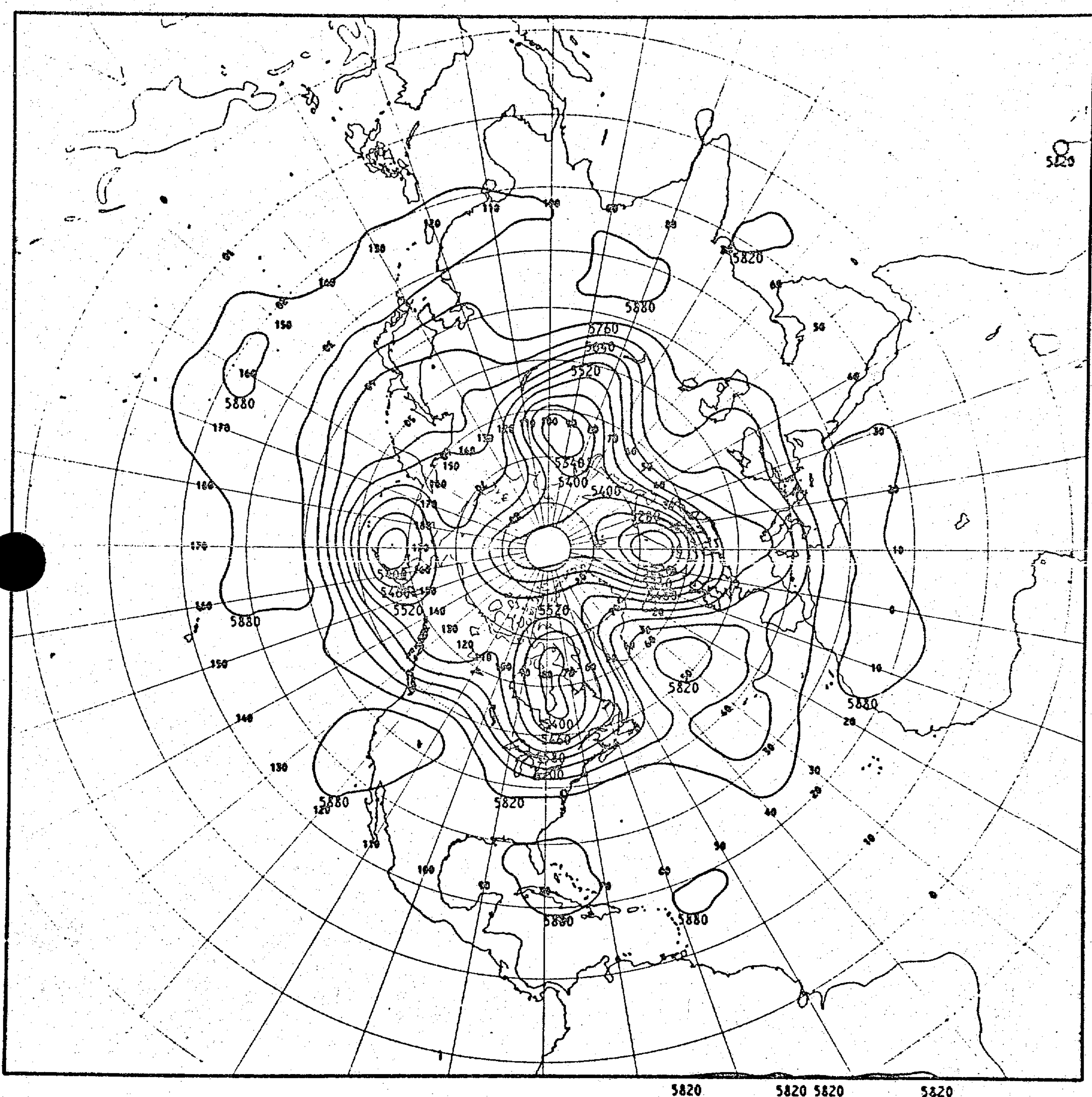
500.00 MB HGT FOR 000 HRS AFTER 00Z 1 SEP 76 12HR

Figure 42



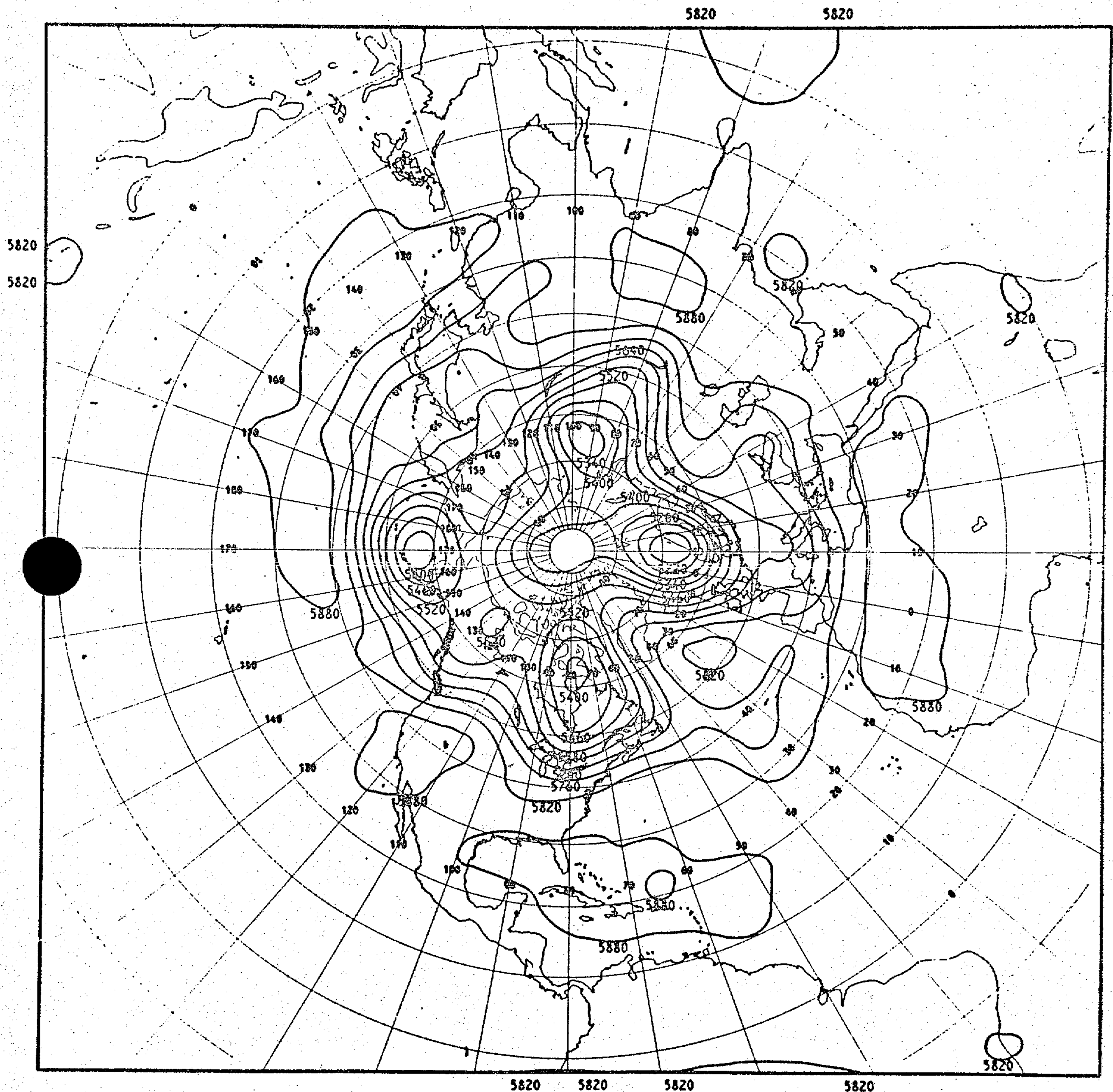
500.00 MB ΔHGT FOR 000 HRS AFTER 00Z 1 SEP 76 06HR - 12HR

Figure 43



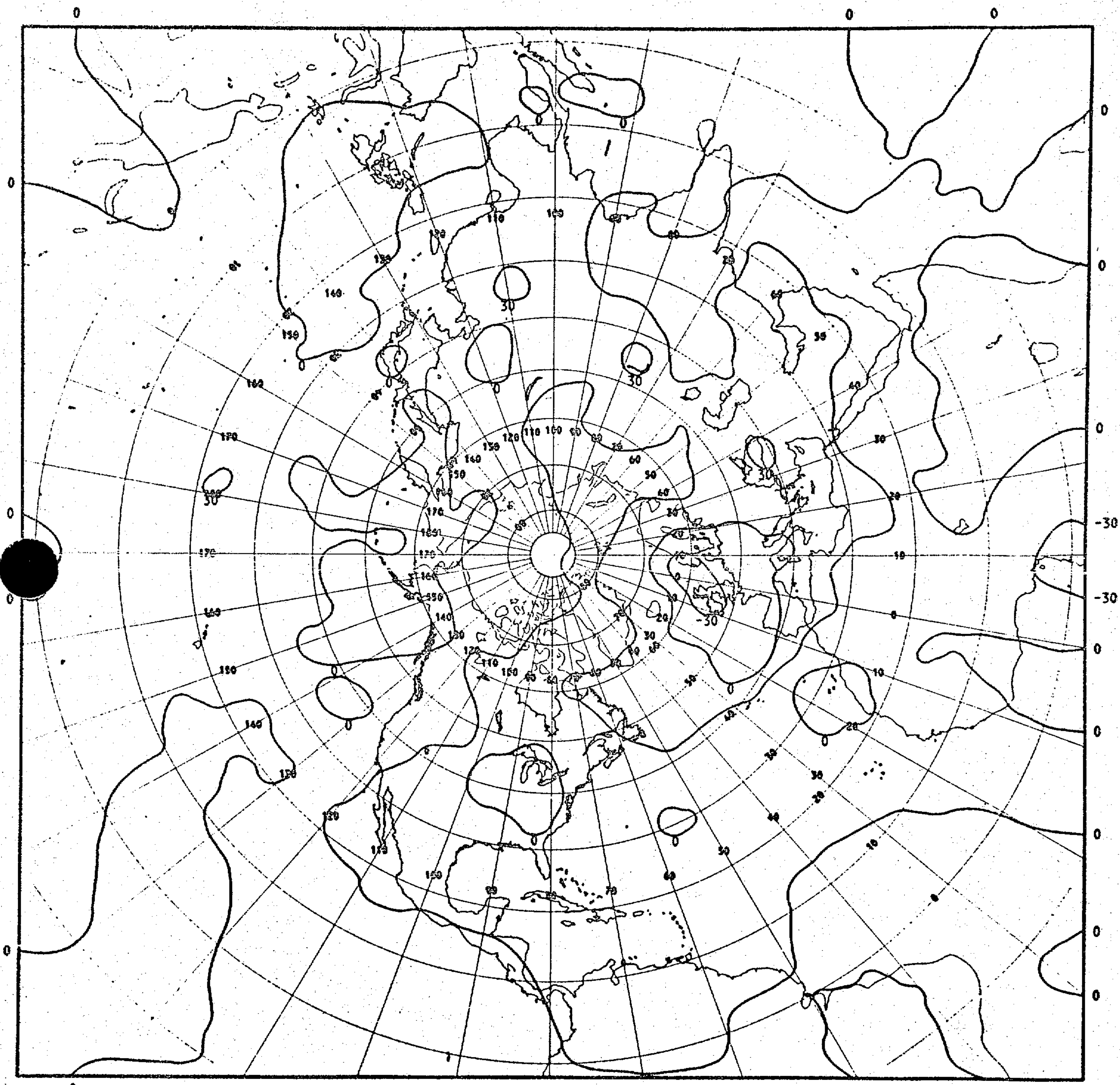
500.00 MB HGT FOR 024 HRS AFTER 00Z 1 SEP 76 06HR

Figure 44



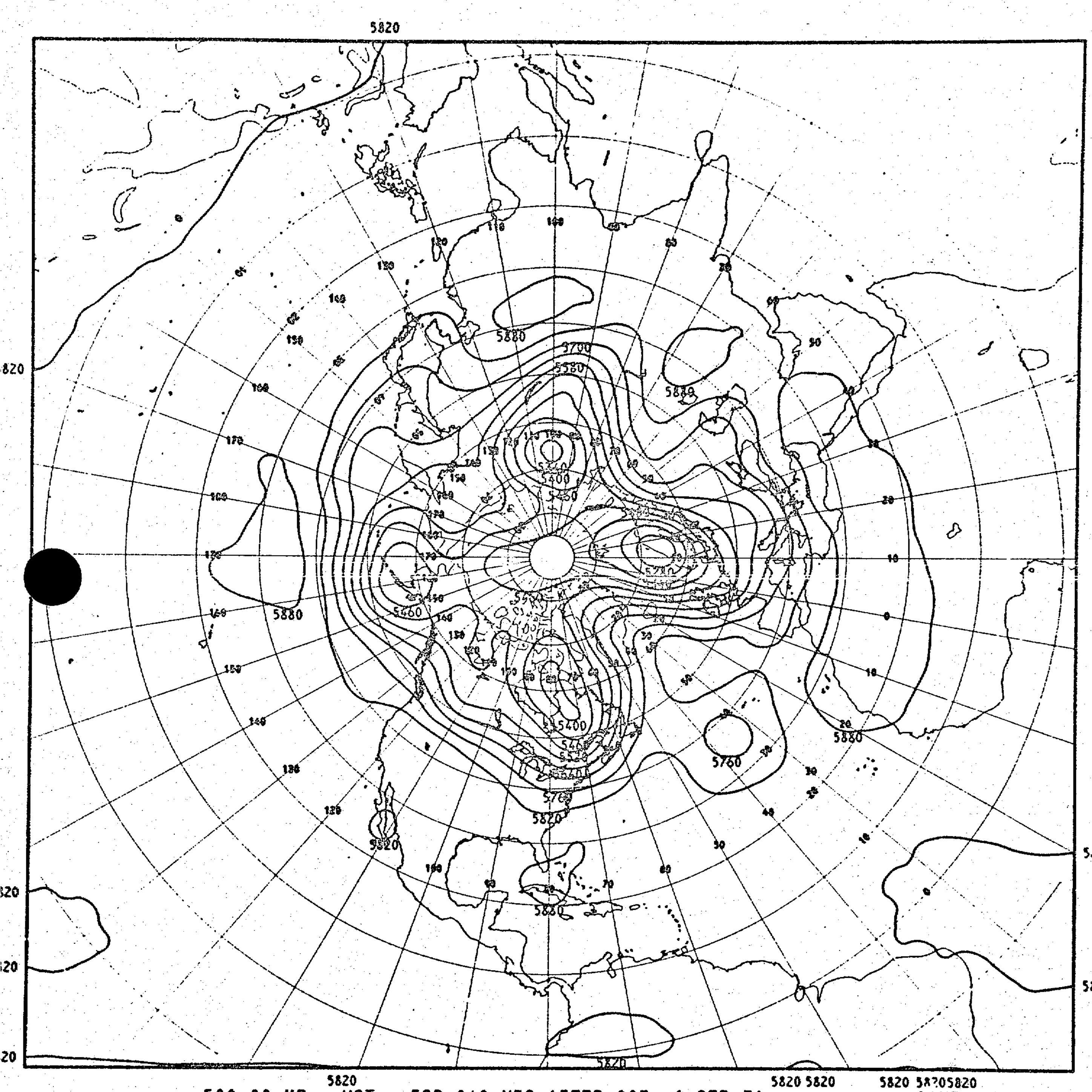
500.00 MB HGT FOR 024 HRS AFTER 00Z 1 SEP 76 12HR

Figure 45



500.00 MB ΔHGT FOR 024 HRS AFTER 00Z 1 SEP 76 06HR - 12HR

Figure 46



500.00 MB HGT FOR 048 HRS AFTER 00Z 1 SEP 76 06HR

Figure 47

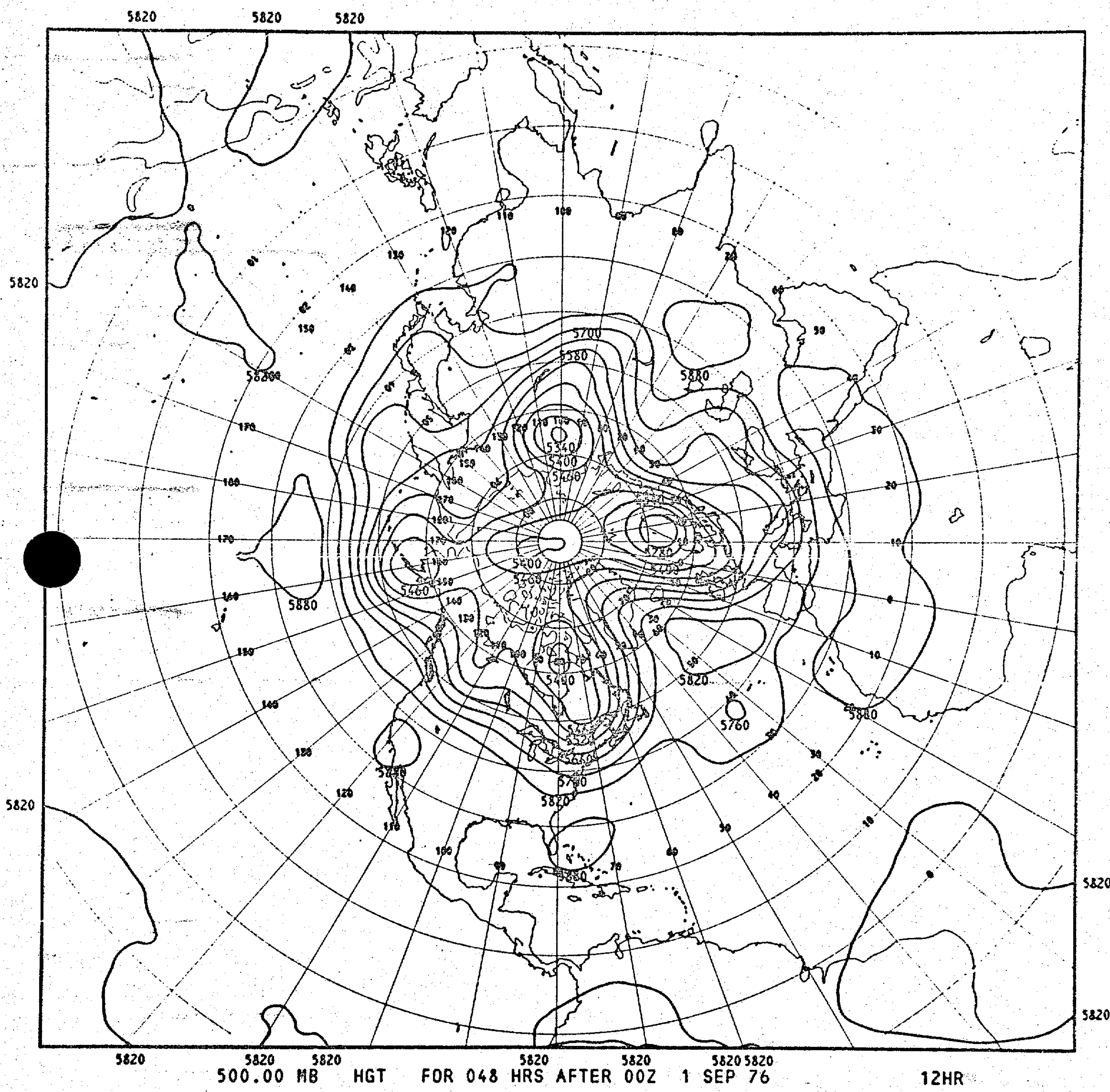
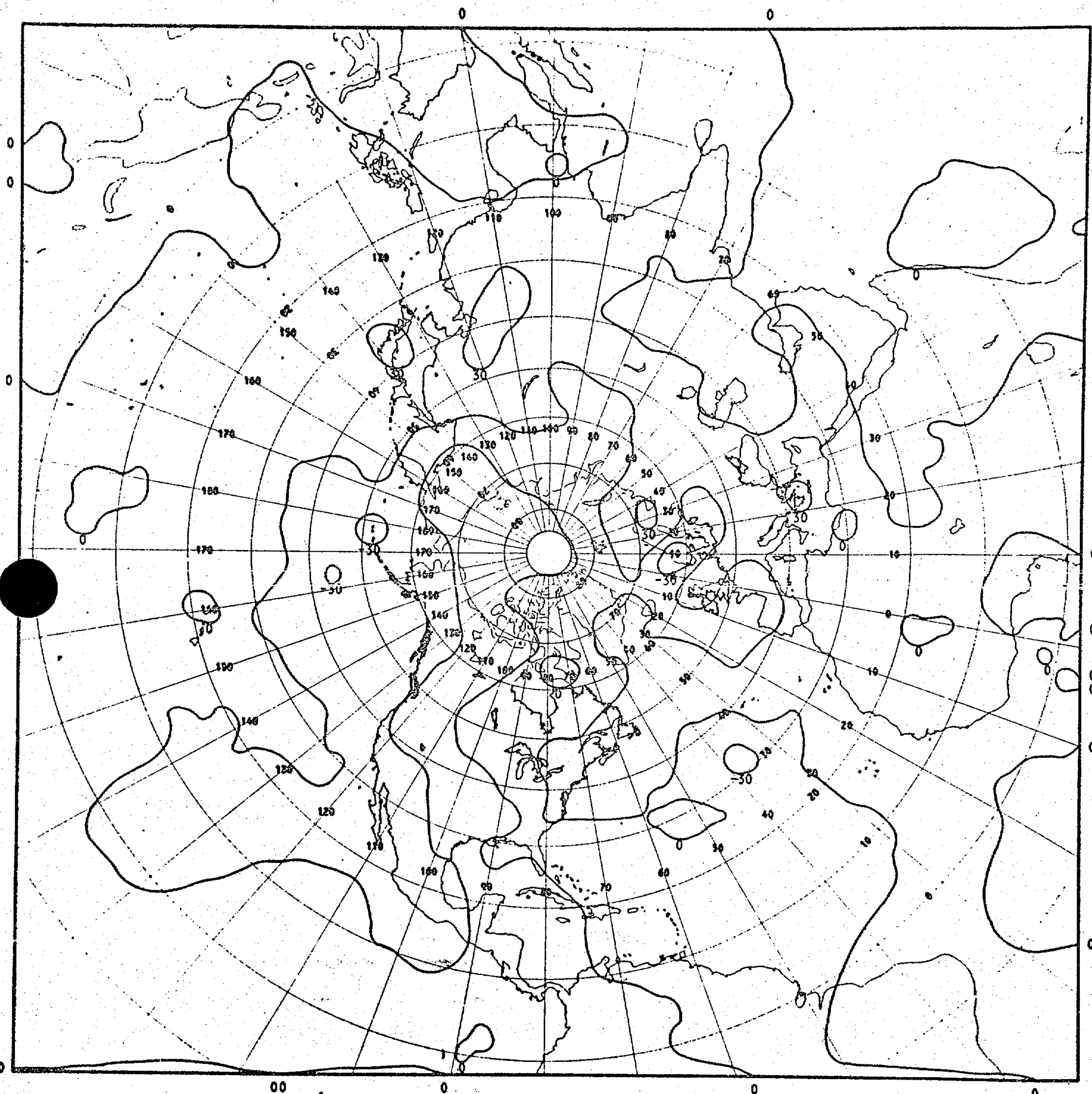


Figure 48



500.00 MB ΔHGT FOR 048 HRS AFTER 00Z 1 SEP 76 06HR - 12HR

Figure 49

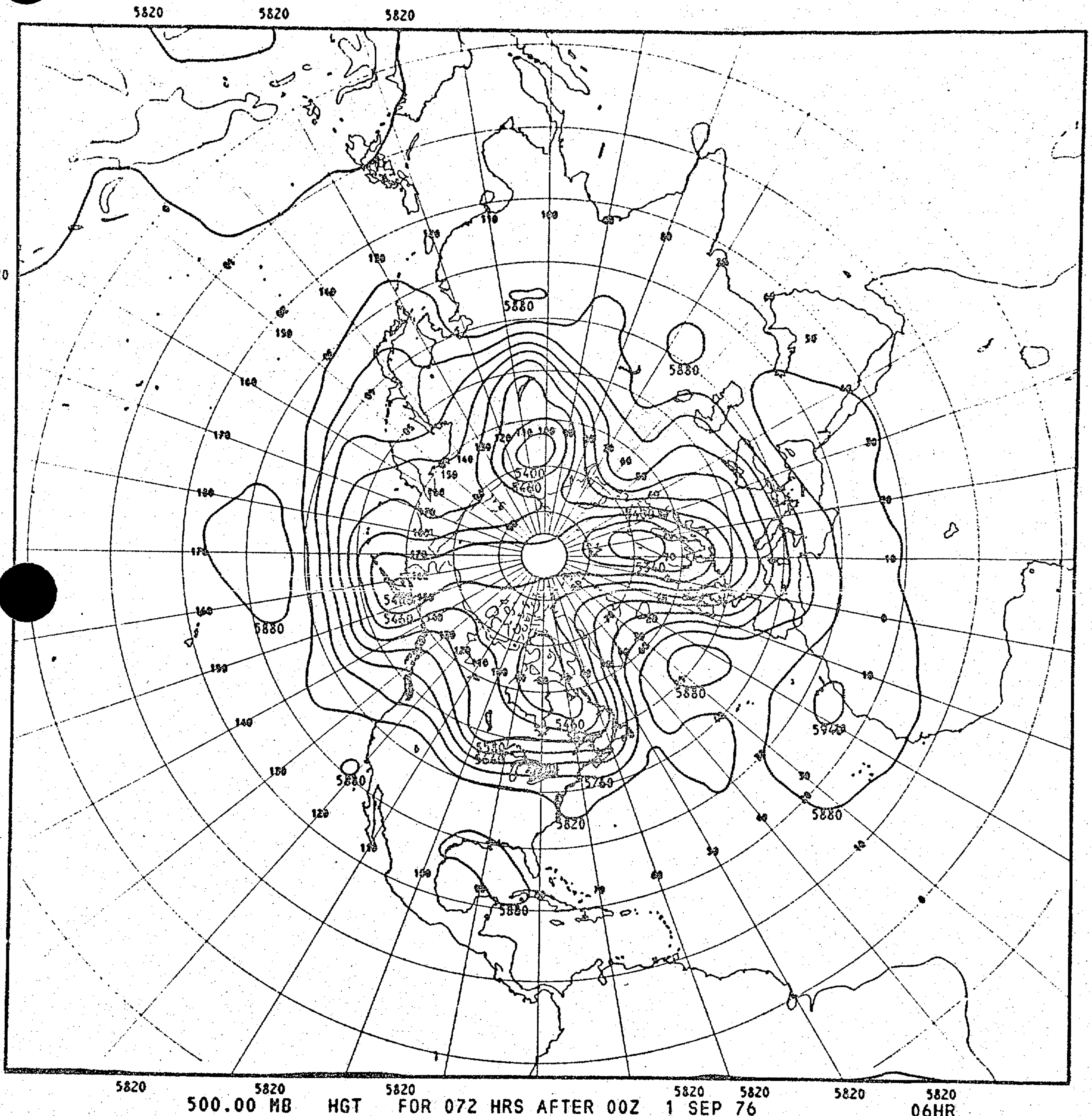
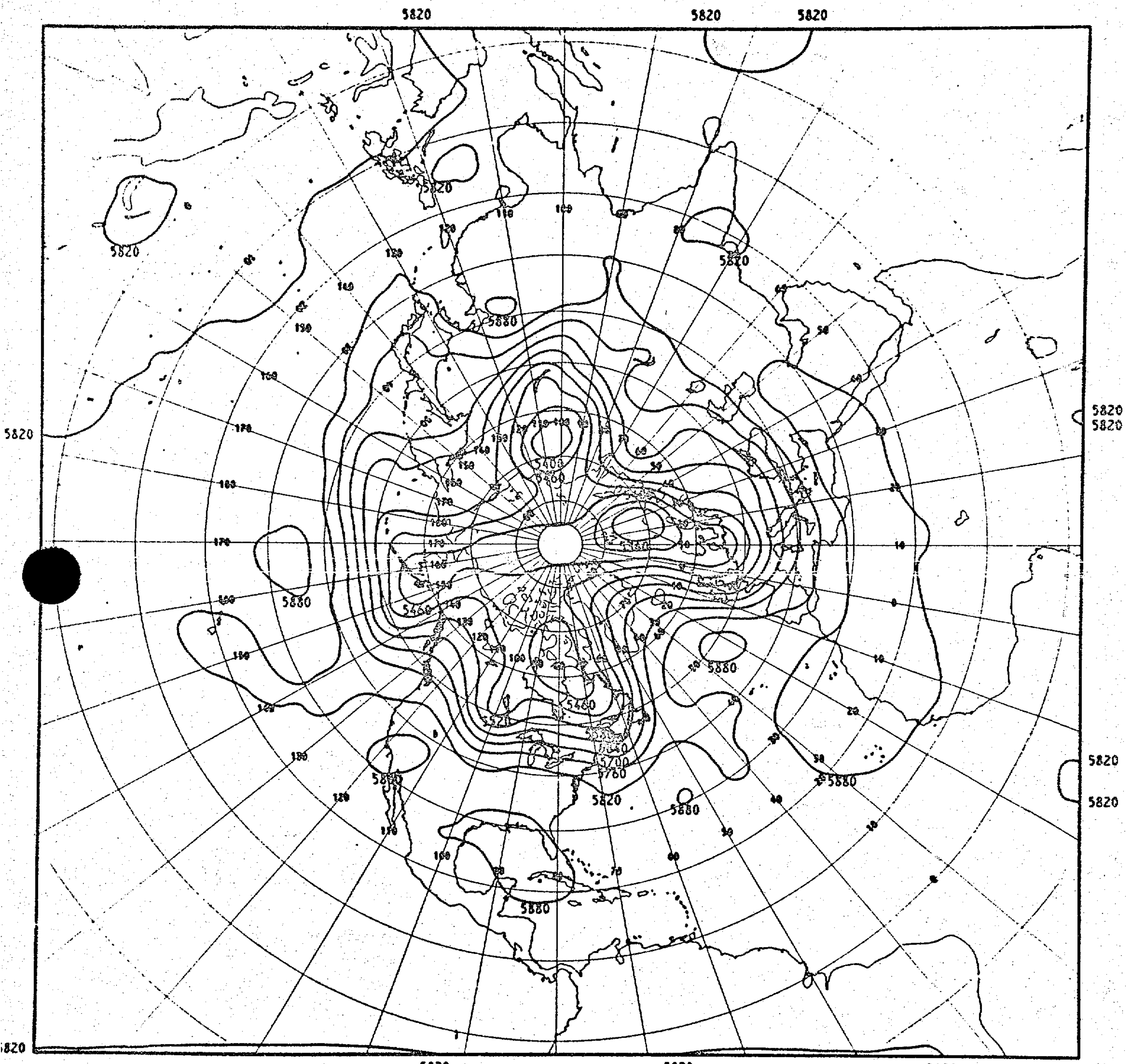
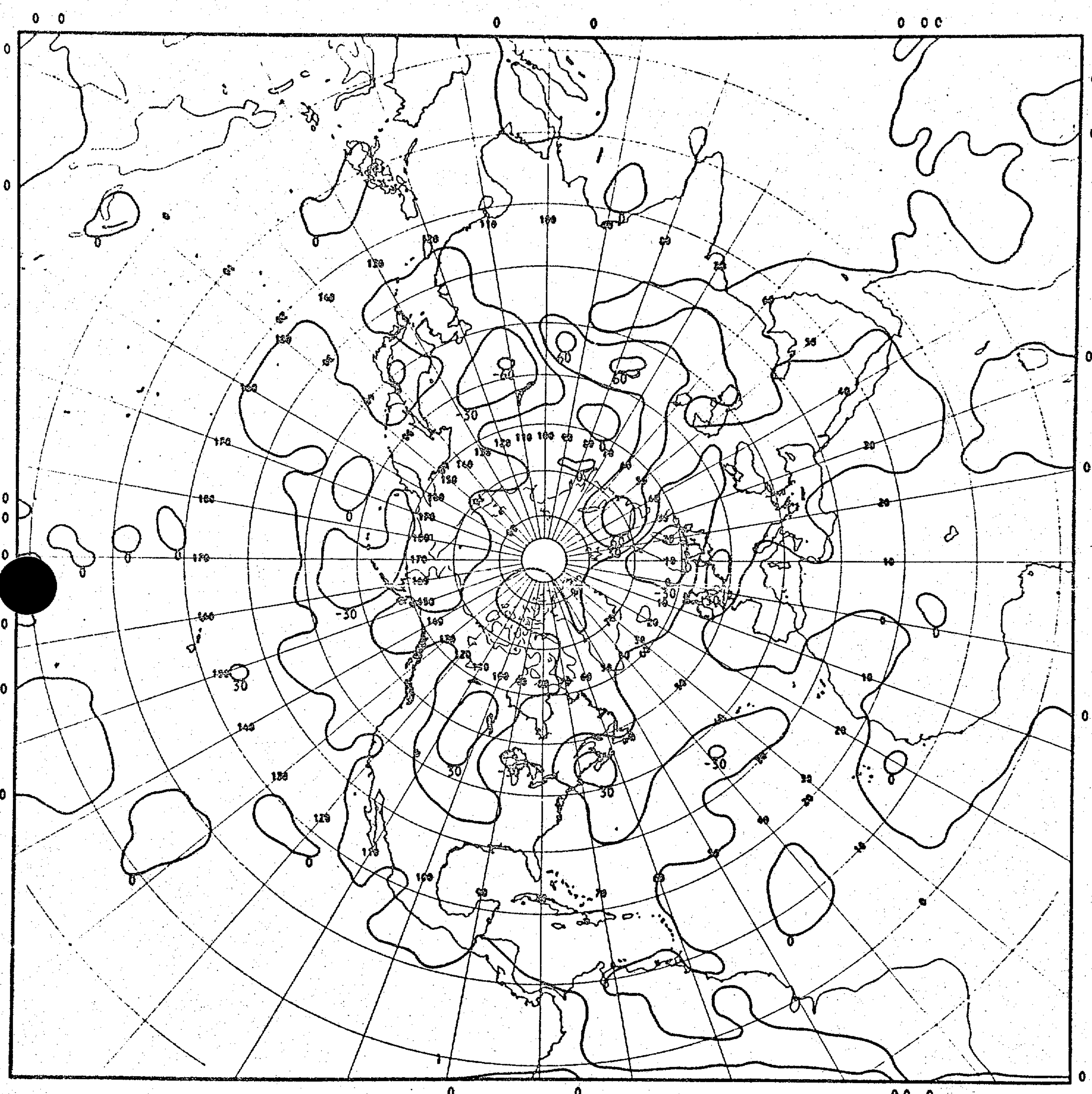

500.00 MB HGT FOR 072 HRS AFTER 00Z 1 SEP 76
06HR
5820
5880
5400
5460
5740

Figure 50



500.00 MB HGT FOR 072 HRS AFTER 00Z 1 SEP 76 12HR

Figure 51



500.00 MB Δ HGT FOR 072 HRS AFTER 00Z 1 SEP 76 06HR - 12HR

Figure 52

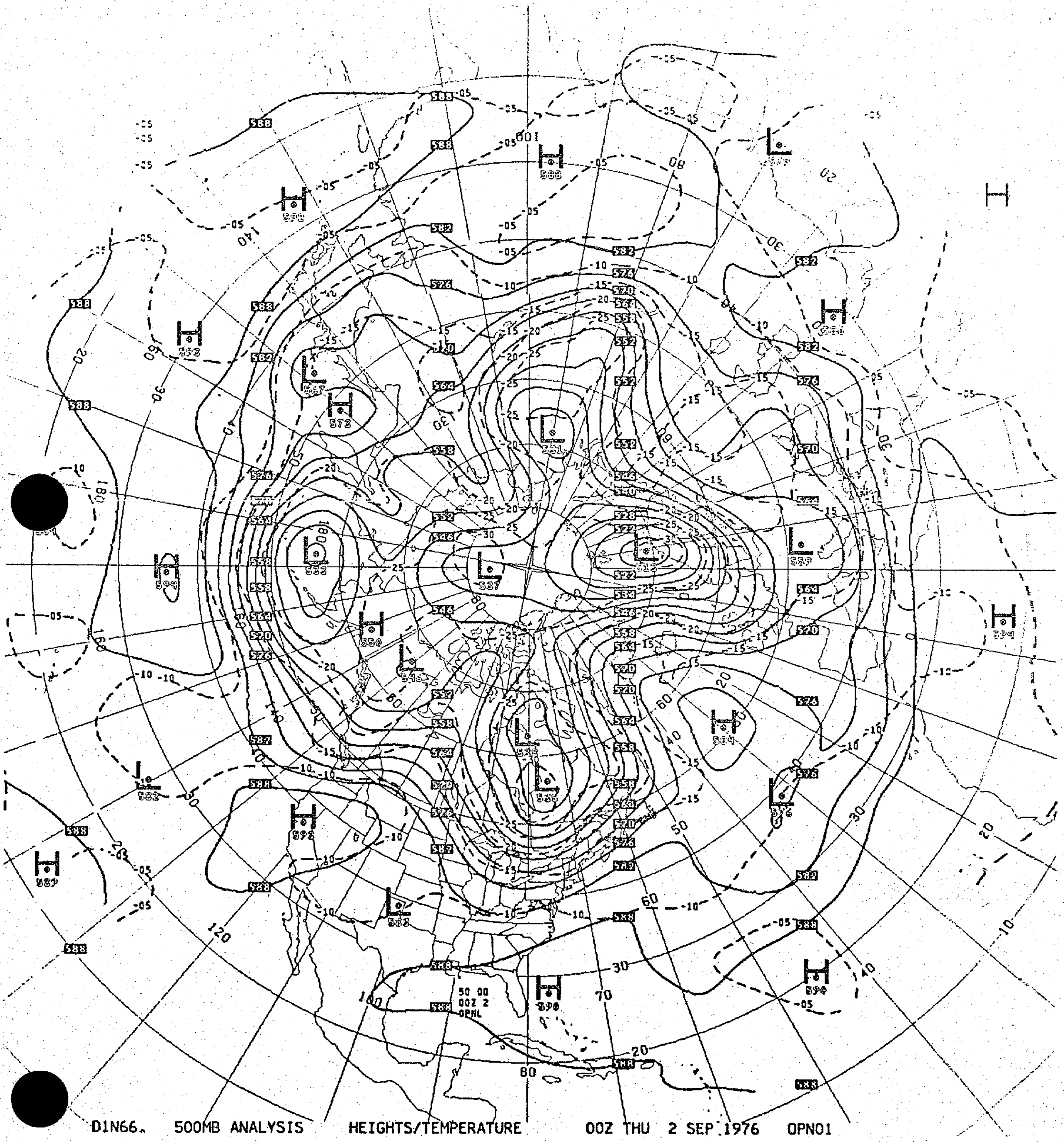

D1N66. 500MB ANALYSIS HEIGHTS/TEMPERATURE 00Z THU 2 SEP 1976 OPN01
50 00
00Z 2
OPNL

Figure 53

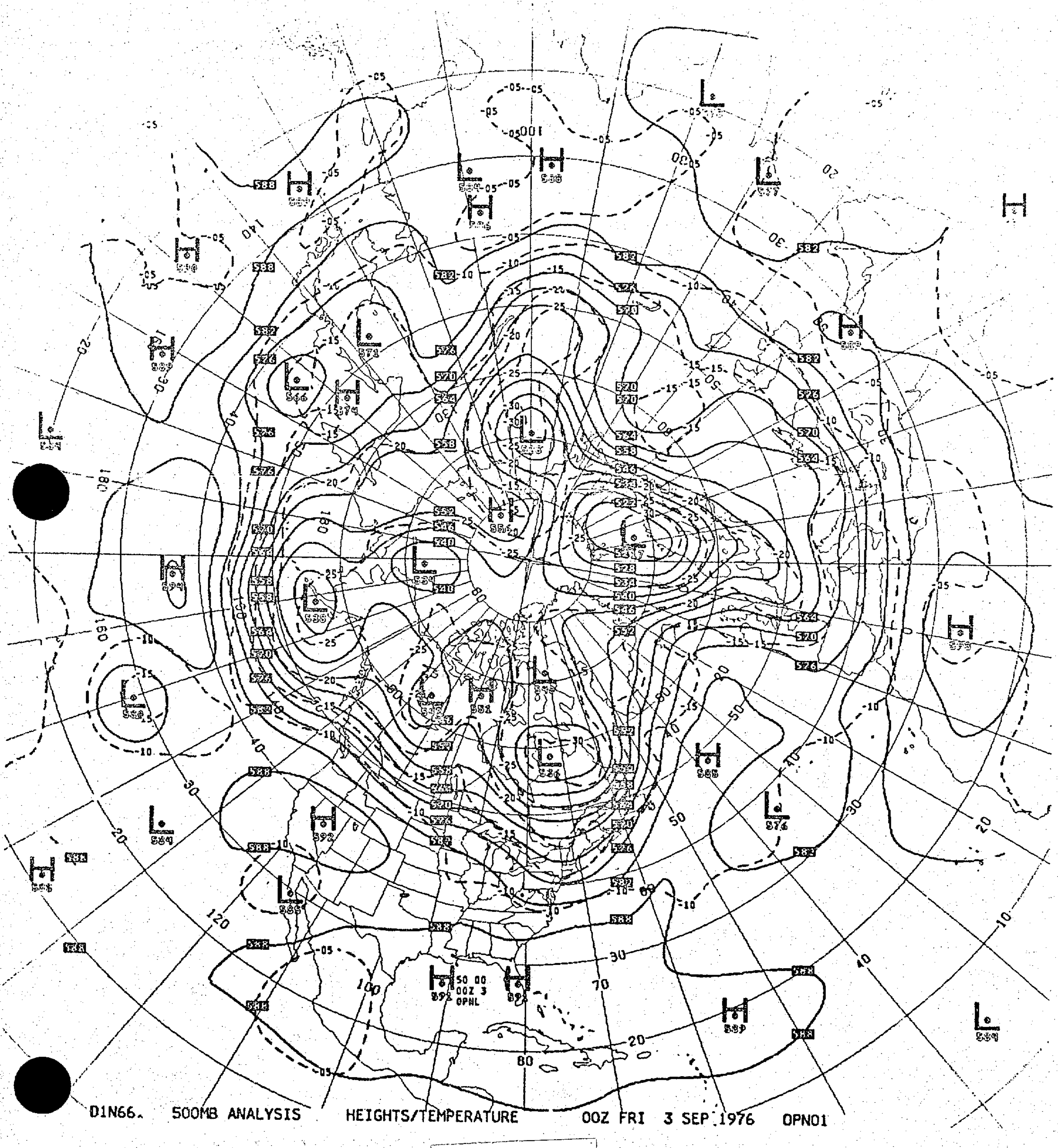

D1N66. 500MB ANALYSIS HEIGHTS/TEMPERATURE 00Z FRI 3 SEP 1976 OPN01

Figure 54

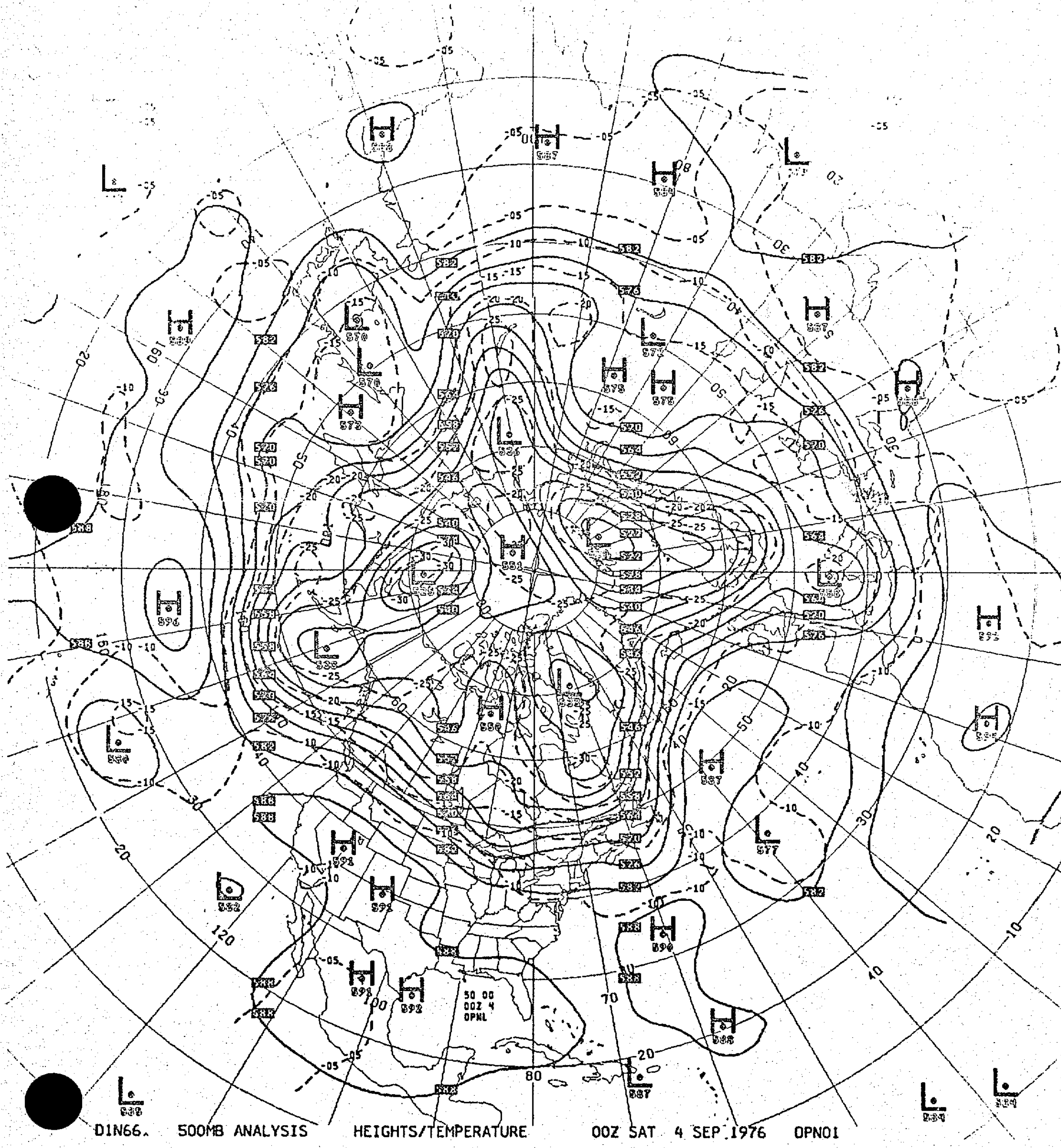
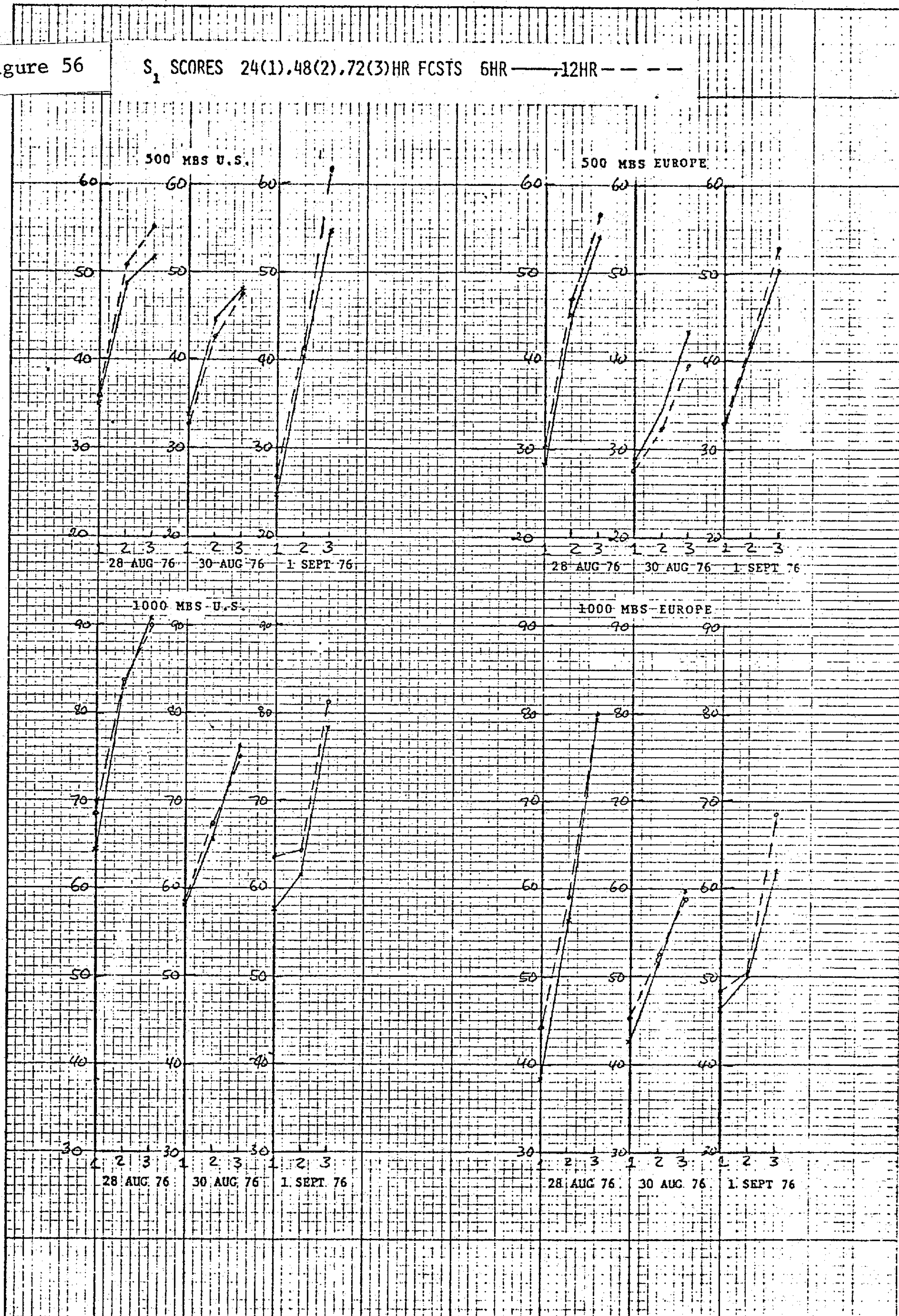

D1N66. 500MB ANALYSIS HEIGHTS/TEMPERATURE 00Z SAT 4 SEP 1976 OPN01
50 00
00Z 4
OPNL

Figure 55

Figure 56


S1 SCORES 24(1),48(2),72(3)HR FCSTS 6HR ——— 12HR – – – –
500 MBS U.S.
500 MBS EUROPE
28 AUG 76
30 AUG 76
1 SEPT 76
1000 MBS U.S.
1000 MBS EUROPE

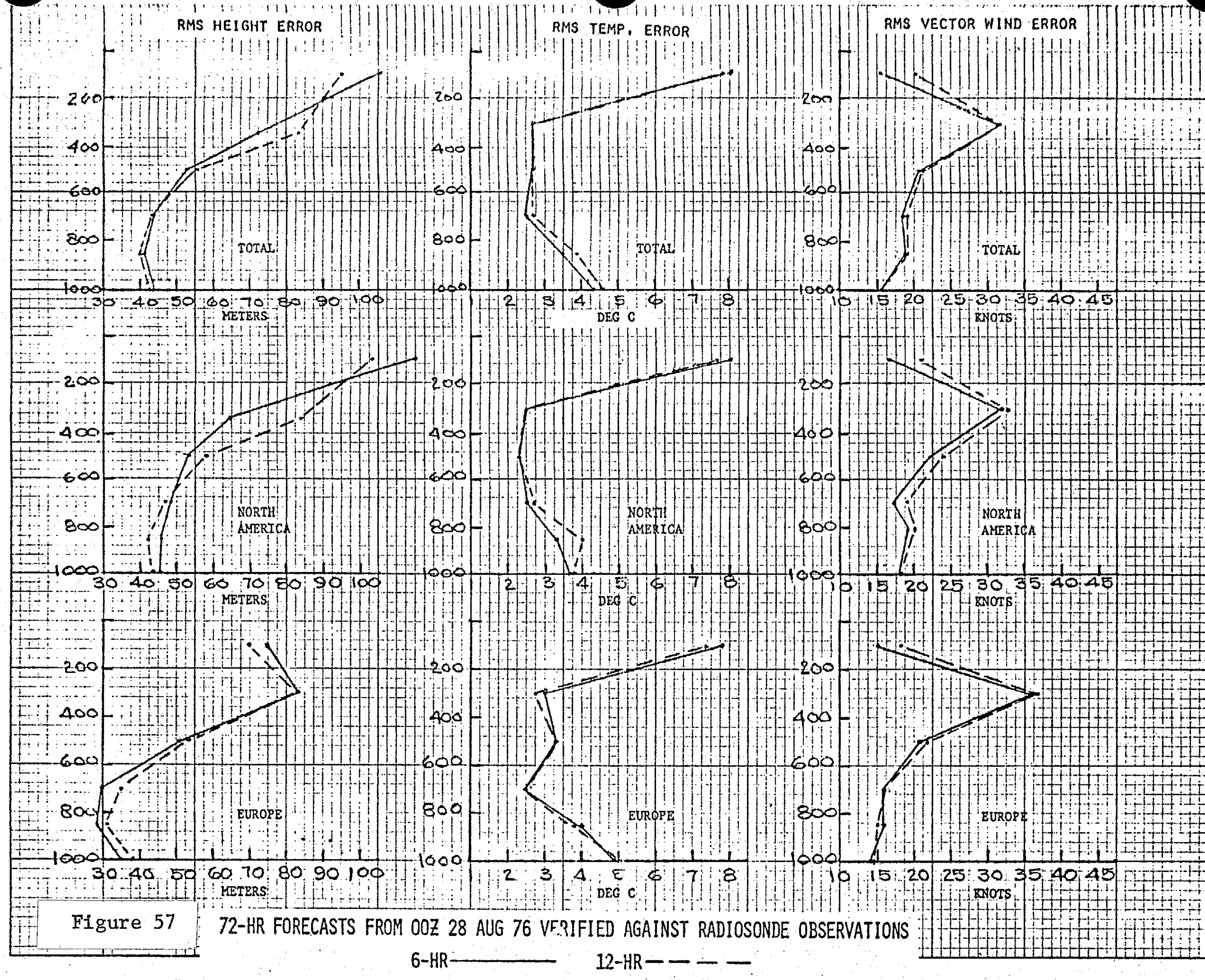


Figure 57 72-HR FORECASTS FROM 00Z 28 AUG 76 VERIFIED AGAINST RADIOSONDE OBSERVATIONS

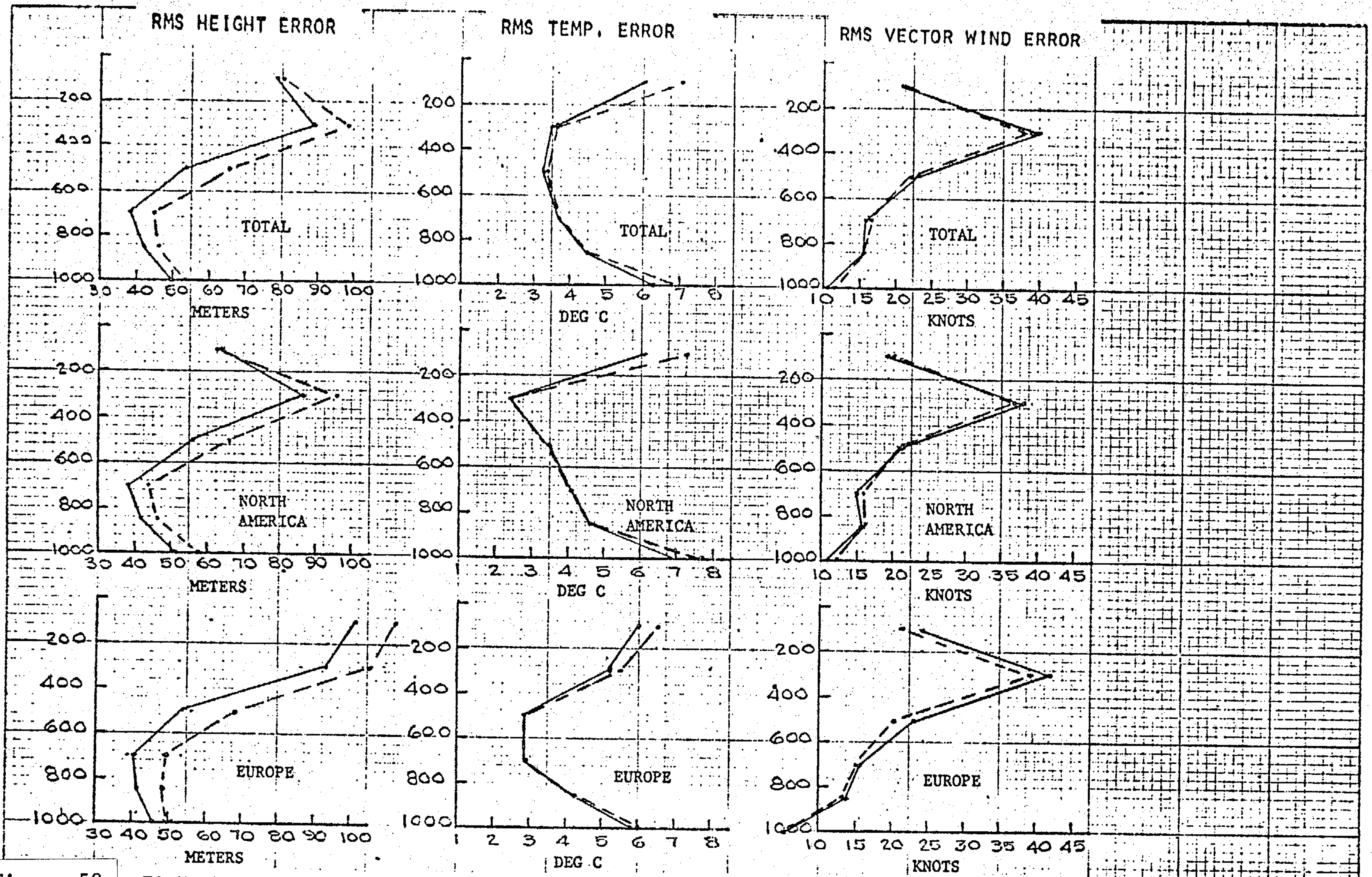


Figure 58 72-HR FORECASTS FROM 00Z 30 AUG 76 VERIFIED AGAINST RADIOSONDE OBSERVARIONS

6-HR ———— 12-HR — — — —

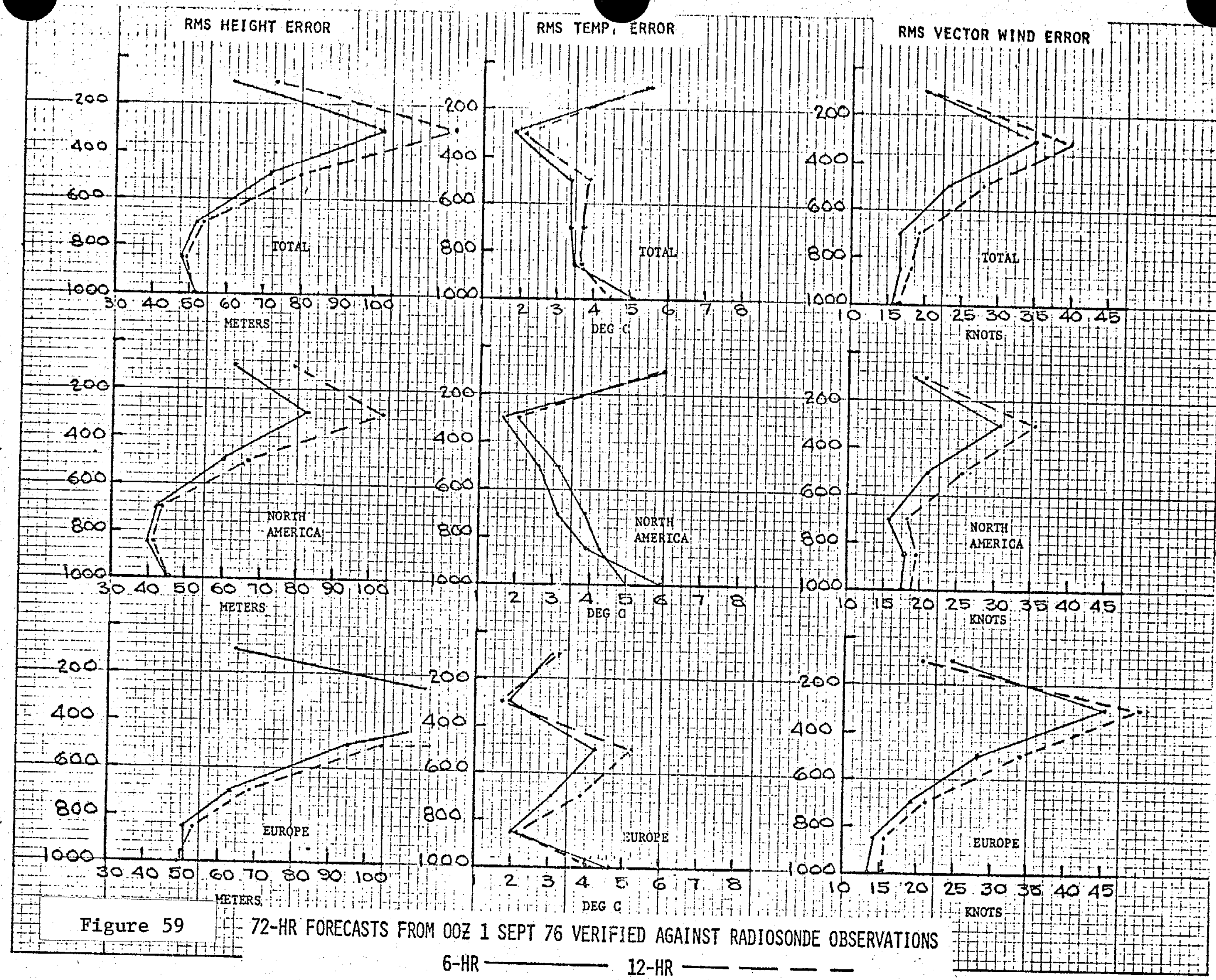


Figure 59 72-HR FORECASTS FROM 00Z 1 SEPT 76 VERIFIED AGAINST RADIOSONDE OBSERVATIONS

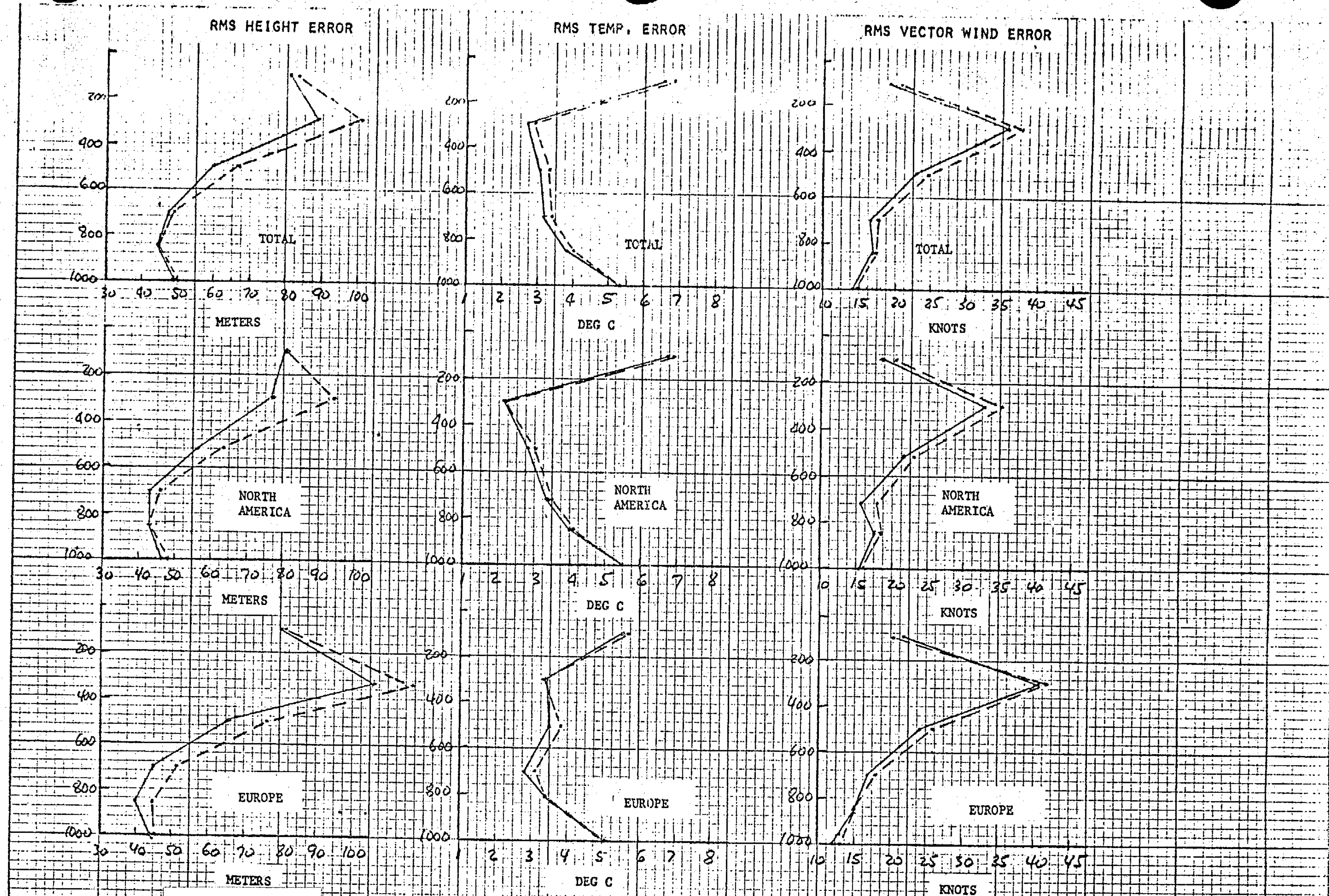


Figure 60

72-HR FORECASTS VERIFIED AGAINST RADIOSONDE OBSERVATIONS (AVERAGE OF THREE FORECASTS)

6-HR ———— 12-HR — — —